Hybrid Stream Solutions

Streambank Management

Design Report:

Streambank Stabilization Method Selection Program

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Abstract

John Redmond Reservoir, a drinking water supply reservoir in eastern Kansas on the Neosho River, has been experiencing serious problems with sedimentation. As part of a Biosystems Engineering (BAE) senior capstone design project at Oklahoma State University, the US Army Corps of Engineers (USACE) Tulsa Office tasked the undergraduate team with devising methods to reduce sedimentation in John Redmond Reservoir. As the greatest source of these sediment loads is erosion from upstream banks in the surrounding watershed, the team determined that the most direct way to address this issue was to provide a solution to stabilize unprotected streambanks in the Neosho Headwaters Watershed. After deciding that merely designing stabilization techniques for one or two banks would not have a large positive impact on the watershed as a whole, the team endeavored to design a system that could provide a recommendation of stabilization methods for any bank in the watershed. The result is a streambank stabilization method selection program (in the form of a macro-enabled Excel workbook) with an accompanying guideline document which acts as a user's manual. The watershed was characterized in terms of common bank slope, typical stream flows (including high flow condition), and typical bank material type in order to make the selection of stabilization methods included in the program tailored to the specific watershed. In addition, Jet Erosion Testing (JET) was carried out onsite in an effort to determine the typical erodibility coefficient and critical shear stress of the banks, which would then be used in erosion model simulations to validate the selection of methods to be included in the program. The erosion modeling was carried out in the Bank Stability and Toe Erosion Model (BSTEM). It is believed that this design could serve as a template for create similar programs in other problem watersheds.

Introduction

John Redmond Reservoir, a drinking water supply reservoir in eastern Kansas on the Neosho River, has been experiencing serious problems with sedimentation. Sedimentation can have numerous ill effects on a freshwater reservoir, including but not limited to decrease in volume of water available for public or industrial use (particularly important here, as the reservoir provides cooling water for a nuclear power plant), decrease in recreational opportunities on the reservoir, and ecological disturbances due to the loading of pollutants which are also carried in on sediment. The reservoir has currently lost about 52% of its storage volume due to sedimentation, from an original capacity of 82,000 ac-ft. The sedimentation rate is estimated at about 740 ac-ft/yr. (KCARE/KSRE, 2010) Though the USACE is planning to dredge the reservoir in 2015 in order to return it to its former capacity, it is crucial that this valuable freshwater source retains its full capacity in future years, as the dredging of an inland lake is a costly and inconvenient solution which is not viable as a preferred method of reservoir maintenance against volume reduction.

As part of a Biosystems Engineering (BAE) senior capstone design project at Oklahoma State University, the US Army Corps of Engineers (USACE) Tulsa Office tasked the undergraduate team with devising methods to reduce sedimentation in John Redmond Reservoir. The greatest source of these sediment loads in the river is erosion from banks within the Neosho Headwaters Watershed, just upstream of John Redmond Reservoir, rather than from overland runoff from the surrounding agricultural land. (KCARE/KSRE, 2010) Therefore, the most direct way to solve this problem is through stabilization of streambanks against fluvial erosion and mass wasting. **Thus, the team identified their problem statement as such: to create watershed-specific guidelines for innovative, cost-effective designs to most effectively stabilize streambanks upstream of John Redmond Reservoir in order to reduce sedimentation in the reservoir, thus prolonging the life of the reservoir.**

The primary result of this design project was a Microsoft Excel-based spreadsheet program (Neosho Headwaters Stabilization Technique Selection) which uses macros in an automated process to select streambank stabilization methods for any bank in the watershed, accompanied by a document (Neosho Headwaters Streambank Stabilization Guideline) which provides explanations and examples of program use. This report will include the design constraints given by the project client and developed by the team, as well as design iterations and a detailed description of the final program design. Also included will be descriptions of the team's determination of watershed characteristics in order to design a program that is specific to the Neosho Headwaters Watershed, a list of what streambank stabilization methods were chosen to be included in the program matrix and the criteria that determined their inclusion or exclusion, and the validation of those methods' inclusion in terms of applicability to erosion control in the watershed.

Statement of Work

This section details an overview of the general approach to the problem on the part of Hybrid Stream Solutions.

Scope of Work

The scope of work for this project includes: planning; case study site selection; characterization of physical parameters of the stream and streambanks, both through literature and database review and physical and field testing done by the team; extensive literature review and analysis of streambank stabilization methods already in accepted use, including possible patent conflicts; review of federal (especially USACE) guidelines for streambank stabilization; creation of a computer tool by which to judge the applicability of current methods to the sites in question; the design or modification of methods or combinations of methods; and validation of optimum methods through the use of the Bank Stability and Toe Erosion Model (BSTEM). Not included in the scope of this work is the actual restoration or construction of stabilized streambanks at the chosen case study sites on the Neosho River.

Period of Performance

The period of performance for the project began in September 2014 and ended on 8 May 2015. All tasks were completed within this timeframe.

Place of Performance

Jet erosion tests (JETs), rapid geomorphic assessments, and soil sampling took place onsite on Neosho River streambanks in the Flint Hills National Wildlife Refuge near Hartford, Kansas, in the Neosho Headwaters Watershed area upstream of John Redmond Reservoir. The majority of work took place in Stillwater, Oklahoma, using the resources of Oklahoma State University. Intensive computer modeling will took in computer labs in the Biosystems and Agricultural Engineering (BAE) department. Particle size distribution analysis completed with retrieved soil samples was done in the BAE environmental laboratories.

Deliverables Schedule

A fully-revised, complete, and representative design guidance manual and a macro-enabled recommendation program were due the first week of May 2015. The manual includes detailed recommendations and specifications for installation, maintenance and cost for four of the most regionally optimum techniques recommended by the matrix. The computer recommendation tool consists of an input/output program for Microsoft Excel. Users can input known stream and streambank characteristics, and the program will output recommended treatments including the benefits and costs of each (e.g., effectiveness for the given bank, financial cost, time of installation, labor intensity of installation, and future maintenance requirements). The purpose of these methods is to reduce sediment loads in the river.

Design Constraints

This section accounts for the design constraints set for this project In order to optimize the value of the recommendation program in order to optimize the value of the recommendation program.

Client Requirements

The client requirements given by the USACE Tulsa Office were as follows:

The recommended streambank stabilization methods must be applicable to streambanks on federal land upstream of John Redmond Reservoir. The methods should be chosen to reduce the sediment load which enters the Neosho River from eroding streambanks for the purpose of protecting the capacity of John Redmond Reservoir. Any recommendations for streambank restoration must take into consideration federal regulations regarding construction and streambank management. USACE prefers stabilization methods which can be combined or modified to meet the needs of specific streambank systems in the region. Final deliverables should include the method selection program as well as a guidance document detailing a cost/benefit analysis and detailed explanations of recommended treatments.

Developed Constraints

In order to recommend the most effective methods to reduce streambank erosion, the methods included in the program must be optimized for the particular region in question. This requires knowledge of the watershed characteristics. Characteristics under consideration include: a general understanding of high flow behavior of the Neosho River; bank soil types, including particle size distribution; bank soil erodibility and critical shear stress; and bank stage of channel evolution. The methods selected in the recommendation program are validated in BSTEM to meet or exceed a confidently stable bank factor of safety of 1.3 with no failures for a worst case hypothetical scenario of two high flow storm events in a month, with these high flow events nearly meeting but not exceeding full bank height.

Design Approach

This section accounts for the initial design approaches, as well as a detailed description of the final design.

Early Design Approaches

The initial design approach was to provide detailed plans for the installation and construction of specific stabilization designs for two of seven priority sites located in the Flint Hills National Wildlife Refuge, which is within the Neosho Headwaters Watershed near Hartford, Kansas. The number (two) was chosen as a rough estimate of what could be accomplished to satisfaction during the time allotted for the course (two semesters). These sites taken from 32 priority sites originally identified by the Kansas Water Office and agreed upon by the USACE. An extensive literature review was performed to become familiar with a wide range of stabilization methods including those utilized by the USACE and any patented innovations in the field. Web soil surveys and initial site surveys were conducted to determine the highest risk banks for the designs and characterize the conditions at those banks. It was decided that this approach, to only specifically stabilize a few sites, would limit the overall effectiveness of the design to significantly reduce sedimentation in the watershed as a whole and thus also in John Redmond Reservoir by only tackling a very small portion of the problem.

The next approach was to take the information from site surveys, field testing, and laboratory soil testing and conduct a general characterization of all the sites. This would allow for a more generalized stabilization plan for the entire watershed and thus increase the overall effectiveness of the design to reduce sedimentation in the area. This design would include detailed descriptions of four or five stabilization methods customized for the watershed. A cost/benefit matrix, comparing each of the plans, would also be included. This matrix would detail monetary costs as well as the effectiveness of each method to stabilize erosion across each level of the bank. This would allow the user to make an informed method selection for the specific situation at any bank in the watershed. However, this approach would rely on the user to understand erosion processes and the importance of certain bank and stream parameters. It was decide to automate the matrix to remove the need for manual decision-making and to make the process more user-friendly by creating a macro-enabled Excel program.

Final Design

The final design consists of the Neosho Headwaters Streambank Stabilization Guideline document and the Neosho Headwaters Stabilization Technique Selection program.

Program Details

The selection program is a macro-enabled Excel spreadsheet which accepts user inputs of bank and stream characteristics and outputs a recommendation table. The program consists of three tabbed sheets: the “Inputs” sheet, “Output Matrix” sheet, and “Treatments” sheet.

The “Inputs” sheet asks the user to enter known characteristics of the bank and stream in the chosen area as well as any specific engineering preferences or site limitations. The required inputs include the following: in the bank properties category are current bank slope, bank height, bank material (drop-down choice), and presence of seepage (yes or no); in the stream properties category are peak discharge, peak stage, width at peak stage, and peak flow season (drop-down choice); in the erosion processes present category are a series of yes or no choices – toe erosion or undercutting, mass wasting or slumping, fluvial erosion, gullies or rills, and runoff – which represent the erosion processes that the user notes are or seem to be present at the bank; and in the engineering preferences category are three drop-down menus which inquire about type of engineering design preferred (structural, biological, combination, or no preference), as well as whether the site is accessible to large equipment and, if so, whether the user would consider having the bank re-graded.

The program compares these inputs with specifications and benefits from the treatments on the hidden “Treatments” sheet. Each treatment is given a score weighted by its ability and overall effectiveness to meet the specifications entered by the user. This comparison allows the program to select the top three beneficial treatments for the area and then shows these treatments in the matrix on the "Output Matrix" sheet. The matrix allows the user to see the comparison among the selected treatments and the costs associated with each, to guide the user in the final decision-making process. Specifications listed for each of the top three selected methods on the "Output Matrix" sheet include erosion processes the method will protect against, the location of the protection on the bank, the required slope, whether re-grading is necessary, allowable velocity and shear stress of the method, whether it improves drainage (thus limiting seepage), complexity/intensity, ability to be combined with other methods, known environmental benefits, limitations, best season for installation, and best materials for installation.

Please see Appendix B for full screenshots of the program "Input" and "Output Matrix" Worksheets.

Guidance Document

The document details the ranges of streambank characteristics found in the watershed. It then describes the stabilization methods and combinations of methods selected in the accompanying program. These details include uses, purposes, benefits, costs, complications, optimum situations, etc., along with estimations of how bank erosion will be affected when implemented on real streambanks in the Neosho Headwaters area.

Work Breakdown Structure

The following was the hierarchal breakdown of work for our team in terms of objectives and deliverables, including tasks required for the completing of each set and subset.

1. **Neosho Headwaters Streambank Stabilization Guideline:** This document will outline the problem presented by sediment loads in the Neosho River and emphasize the necessity of these methods with respect to the capacity of John Redmond Reservoir. It will then outline use of the program in four case studies for streambank stabilization at four chosen priority

sites in detail, including the concepts behind each design and information from validation testing of the designs. Each design will be backed by an explanation of why the processes in that region optimize that method or combination of methods, including data from both site characterization and BSTEM validation. Each design will include guidelines for installation, maintenance, and cost of that method, and suggestions for more detailed descriptions in the literature.

1.1. Knowledge of Regional Sites: Characterization of bank and bank-river system parameters specific to the Neosho Headwaters Watershed is necessary to determine optimum stabilization designs for the region.

1.1.1. Priority Site Selection: Priority site selection has been completed based on recommendation in the WRAPS document for sediment load reduction. The Kansas Water Office assisted with recommendations specific to those sites within the Flint Hills National Wildlife Preserve.

1.1.2. Rapid Geomorphic Assessments (RGAs): The Channel Stability Index calculation completed through this method not only gives another perspective on bank priority or urgency of stabilization, but also allowed the team to better understand the processes at work in erosion of these particular banks, and the differences between banks in the same priority ranking in this region. These were completed following the first site visit in November 2014.

1.1.3. Flow Data: Obtained from the USGS stream gauge database.

1.1.3.1. Hydrologic Frequency Analysis: A characteristic 100-year peak flow (as well as several lower return period peak flows) has been determined for this reach of the Neosho using the Log Pearson Type III method of hydrologic frequency analysis as recommended by the USGS for rural streams and stream reaches. This will aid in scale modeling and give an idea of flow velocity and fluvial shear force the stabilized bank will need to resist.

1.1.4. Bank Material Characteristics: These include but are not necessarily limited to the soil type, bulk density, typical moisture content, erodibility coefficient, and geotechnical parameters. These were able to be determined using either onsite tests or soil samples retrieved from the priority sites during the November or March site visits.

1.2. **Knowledge of Methods:** Naturally, a thorough understanding of current methods of streambank stabilization is necessary to best be able to understand which methods are optimum for the region, which methods may be combined, etc.

1.2.1. **Literature Review:** An extensive literature review was conducted in September and October 2014. A summary of the same can be found in the Literature Review section of this report, in addition to a table detailing the uses, benefits, purposes, and complications of each method.

1.3. **Recommendation Program**

1.3.1. **Macro-Enabled Recommendation Spreadsheet:** Along with the guidance document itself, the client will be provided with a program in the form of a macro-enabled Microsoft Excel spreadsheet which will detail the benefits and complications of various optimum methods based on user inputs including but not limited to physical site characteristics. Overall, the spreadsheet will remain specific to the Neosho Headwaters Watershed.

1.4. **Validation by BSTEM:** Erosion data and bank characteristics will be used to validate the applicability of the selected methods to meet the aforementioned reduction rates estimated in the WRAPS document.

1.5. **Documentation**

1.5.1. **Statement of Work:** See the Statement of Work section of this report.

1.5.2. **Fall Semester Report:** A design proposal report must be completed and presented for client approval at the end of the first half of the project timeline.

1.5.3. **Spring Semester Report:** A final design report detailing the team's complete and final decisions with regards to optimum designs and validation results will be presented to the client in May 2015. This is that report.

1.5.4. **Final Guidance Document:** See the first item in this Work Breakdown Structure; this document will be completed and presented to the client in May 2015.

1.6. **Communication:** Results and progress will be communicated on various occasions.

1.6.1. **Fall Semester Presentation:** The design proposal (essentially, the contents of this report) will be presented to the client in an open presentation in December 2015.

1.6.2. **Spring Semester Presentation:** The final design will be presented to the client in an open, official presentation in April 2015.

Watershed Characteristics

This section details the methods of data collection and evaluation to characterize the Neosho Headwaters Watershed in order to create a program specific to the region.

Data Collection

First, any information that could be gathered using existing databases and purely analytical methods was researched. Next, the team conducted a site visit to the Flint Hills National Wildlife Refuge upstream of John Redmond Reservoir.

Figure 1: Site 34 in Priority Group 2 of the Neosho Headwaters Watershed, *personal photo taken during site visit on November 15, 2014.*

Seven of the priority sites in the Neosho Headwaters Watershed were visited on November 15, 2014 to conduct visual analyses in order to better understand erosion processes and bank properties of the reach. Soil testing could not be completed at that time because an early hard freeze had frozen the banks; testing the bank soils at that time would have yielded inaccurate results. Thus, the analyses completed consisted only of conducting rapid geomorphic assessments for each of the priority sites. The priority sites were revisited on March 13, 2015 to take soil samples to for particle size distribution analysis in the lab. In addition, jet erosion tests (JETs) were conducted onsite during the March visit to determine the erodibility coefficient and critical shear stress of the bank soils.

Hydrologic Characterization

Yearly peak flow data for gages near the priority sites was evaluated from the United States Geological Survey (USGS). The USGS stream gage near Americus provided a reliably long record while still being upstream of the site and fairly close. Using the Log Pearson Type III (LP3) method of hydrologic frequency analysis (USGS and KDOT, 2000), characteristic peak flows were calculated for several return periods as a rough estimate of watershed behavior (Haan et al, 1994). As can be seen in Table 1 as well as Figure 2, any methods designed will have to stand up to very high flows during flood events and include adequate protection and stability for any emerging bank vegetation during its establishment period.

Table 1: Return period and predicted peak flows at the Americus Neosho River stream gage

Return Period (yrs)	100	50	25	10	5	2	1
Peak Flow (cfs)	21,600	19,500	17,300	14,000	11,200	6,900	1,100

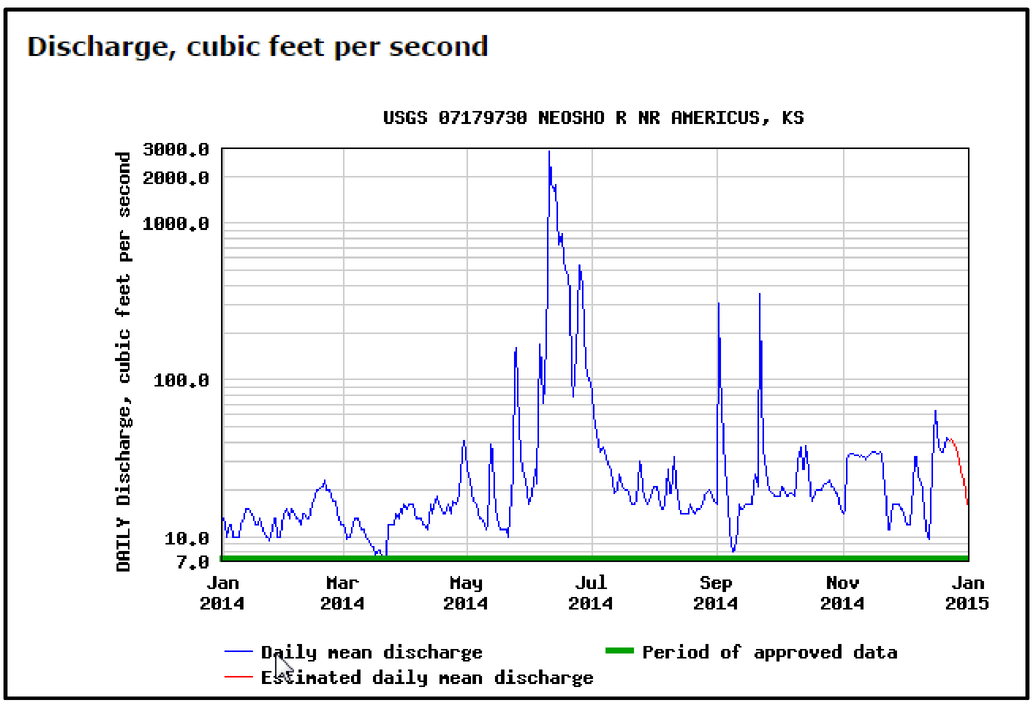

Figure 2: Daily discharge 2014: USGS Americus stream gage

Site Evaluations

Rapid geomorphic assessments combine geometric parameters and visually-assessed bank protection quality, taken on site, in a spreadsheet to compute a channel stability index (CSI) which serves as another measure of stabilization urgency. A higher score represents a channel or streambank which is much less stable. At almost all seven sites, only the bank on one side of the stream shows any signs of erosion. As can be seen in Figure 3, the opposite bank has a much gentler slope and features large trees and established brush of various native species.

Figure 3: Site 29 in Priority Group 2 in the Neosho Headwaters Watershed, *personal photo taken during site visit on November 15, 2014.*

Thus, the scores seen in Table 2 are lower than might be expected in a channel where both banks are in equally poor condition (Heeren et al, 2012). When the priority sites were first identified, they were divided into groups based on urgency, with Group 1 being the most in need of attention and Group 3 being the least. As these sites were identified in 2010, many of the Group 1 sites had already been stabilized by the time this project began, and the team was assigned to remaining sites from Groups 2 and 3. Note that the average score from Priority Group 2 banks is higher than those from Priority Group 3. These overall scores will be useful in determining which banks to design solutions for first. However, the details of the assessments are extremely helpful in determining the major characteristics and erosion processes of the region.

Table 2: Channel Stability Index scores of priority sites

	Priority Group 2					**Priority Group 3**	
Site #	26	27	28	29	30	33	34
CSI	17.5	22.5	21.5	16	22.5	13	19

With this information in mind, the team was able to select four sites (again, this number is based primarily upon an estimation of work that could be completed in the time available) to conduct thorough bank material analysis including JET testing and full particle size distribution analysis for watershed characterization. The sites chosen were based on CSI and accessibility (whether the team could reach the bank to conduct onsite JET testing); sites 27, 28, 30, and 33 were chosen for these reasons.

Bank Material Characterization

Soil Surveys

Soil surveys were conducted using the Web Soil Survey (USDA, 2013), as can be seen in Table 3. These were used only as preliminary research in order to be able to begin program development while waiting for the completion of the particle size distribution analysis.

Table 3: Site soil survey from Web Soil Survey at usda.gov

Sites	Soil Type
26	Reading silt loam, 100%
27	Ivan silt loam, 10% Reading silt loam, 90%
28	Ivan silt loam, 50% Reading silt loam, 50%
29	Chase silty clay loam, 19% Reading silt loam, 29% Ivan silt loam, 52%
30	Reading silt loam, 21.5% Chase silty clay loam, 78.5%
33	Reading silt loam, 100%
34	Chase silty clay loam, 87% Reading silt loam, 13%

Particle Size Distribution Analysis

A full particle size distribution analysis was conducted using soil samples retrieved from each of the four chosen priority sites, including dry sieve and hydrometer analysis. As expected after having handled the bank material, all sites featured a prominent clay component and were mostly fine particles, as can be seen in Table 4. All graphs from the particle size distribution analysis can be found in Appendix C.

Table 4: Soil textures at priority sites.

site	soil texture
27	clay
28	silty clay
30	clay
33	silty clay loam

Jet Erosion Testing

Jet erosion testing (JET) utilizes the jet apparatus, as can be seen in Figure 4, to conduct tests which yield erodibility coefficient, k_d, which is a measure of soil erosion rates, and critical shear stress, τ_c, which is the shear stress required for soil to being eroding. A jet of water is projected perpendicularly into a saturated portion of bank, creating a scour hole. The depth gauge on the apparatus can then be used to measure the depth of scour over time. A Jet Erosion Test Spreadsheet Tool (Daly, 2014) is available for automated data analysis, which yields the two desired parameters based on several analytical solutions to JET data – the Blaisdell Solution, Scour Depth Solution, and Iterative Solution. As the Blaisdell Solution is the currently accepted solution, the team utilized these results in the BSTEM models (discussed in the Validation section), which can be seen in Table 5. Based on these results, which are typical for highly erodible soils, and the results listed in Table 4, it can be concluded that these are, for the most part, highly erodible fine-grained (clay) soils. It should be noted that it had recently rained when JET tests were conducted, so the bank material had already been softened. It is reasonable to suggest, then, that the use of these data in erosion modeling would result in conservative or “worst-case” results, as a dry soil would not be quite so erodible.

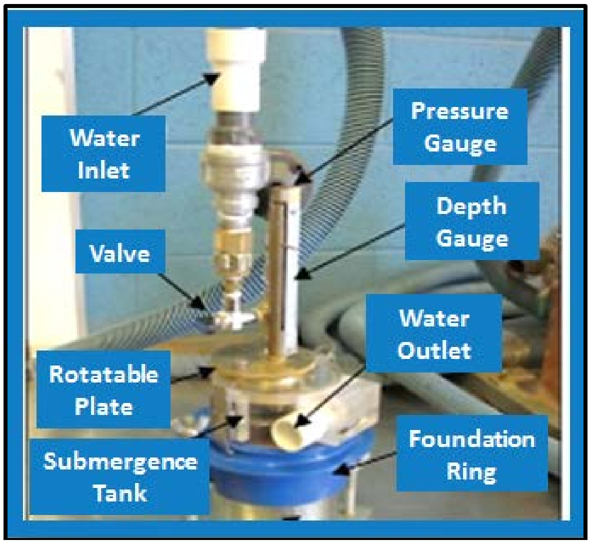

Figure 4: Jet erosion test apparatus diagram

Table 5: Soil erodibility factors and critical shear stress at priority sites.

site	τ_c (Pa)	k_d (cm^3/Ns)
27	0.31	33
28	0.12	46
30	0.08	115
33	0.52	22

Method Selection

The following section describes the process used to select various streambank stabilization methods for the streambank stabilization method selection program.

Literature Review

An extensive literature review was conducted of those streambank stabilization methods currently in practice. Included in the review were what the program calls “biological” methods, which are sometimes referred to as biostabilization or environmentally-sensitive methods, all of which focus on establishing vegetation for root cohesion in banks; “structural” methods, which focus on hard protection techniques as well as in-stream toe protection structures which are not intended to establish vegetation; and “combination” techniques, which utilize hard protection techniques to protect establishing vegetation. The full literature review can be found in Appendix D.

Methods Included

The methods considered by the program include the following: vegetation alone, live staking, joint planting, brush layering, live fascines, brush mattressing, vegetated geogrids, vegetated gabions, tree revetments, rock vanes, riprap, and gabions.

Methods Excluded

Several methods have been excluded from consideration in the final spreadsheet matrix due to inherent incompatibility with the characteristics of the Neosho Headwaters Watershed. These include the erosion control blanket method and the fiber roll method, both of which cannot withstand high flow events; any in-stream toe protection methods which require devices or structures to be placed all the way across the stream; and any methods which do not directly address fluvial erosion or mass wasting from streambanks.

Validation

The following section describes the computer-based erosion modeling used to validate the method selection: the Bank Stability and Toe Erosion Model (BSTEM).

BSTEM Overview

BSTEM contributes to this project by approximating the change in bank factor of safety and bank profile as a result of high flow storm events. First, a BSTEM profile was created to be representative of the priority sites, and the model was run without adding any shear strength to approximate a stabilization method. Then, BSTEM was run again while applying each of the stabilization methods chosen for our recommendation program. The profiles without the stabilization methods were then compared to those with the methods. Comparing these profiles provides a visual understanding of how the stabilization methods might affect the geometry and overall soil erodibility of the priority sites. The bank factor of safety given over time, including any failures, allows for an evaluation of increase in bank stability for a given protection method. More technical information about BSTEM can be found in Appendix E.

BSTEM Model

BSTEM requires the user to input quite a lot of information, including detailed original bank geometry, bank material characteristics, and an input hydrograph to provide the impetus for the simulated erosion. The original bank geometry used in the models was designed to represent one of the priority site banks, with a steep slope and little to no toe. This was then altered for the banks with protection to represent a bank with a 3:1 slope (H:V) according to USACE practice. The bank material characteristics and geotechnical parameters were retrieved from typical values available in BSTEM, using the soil characterization previously completed. For instance, for site 27 we would input the default values for a clay soil. In addition, the bank can be split into five layers to simulate slight (in this case) differences in geotechnical parameters up and down the bank. Erodibility coefficient and critical shear stress were taken from the JET erosion test results. A month of hypothetical hydrologic data was then constructed to simulate two high flow events in a single month, one at the beginning of the month and one 2/3 of the way through the month. This high flow event was designed to reach nearly bank height and then recede back to base flow over the course of 48 hours.

The results of BSTEM are numerous, including many different erosion plots and calculations. For the purpose of this project, the focus is the bank factor of safety with time and the new or eroded bank profile. The bank factor of safety is calculated as a ratio of the resistive force of a bank to the driving forces against it, incorporating such parameters as pore water pressure, the weight of each soil layer, and the bank geometry. (Langendoen, 2013) There are two ranges of bank factor of safety: unstable or highly erodible from 0 to 1.3 or stable or highly resilient at any value greater than 1.3. BSTEM accounts for a combined factor of safety taking into account the possibility of horizontal, vertical, and cantilever shear failures.

BSTEM Results

When the BSTEM results were completed it was found that the critical shear stress given in the literature for various protection methods was great enough (usually between 50 and 150 Pa, as compared to less than 1 Pa for loose soil – see Table 5) that, when combined with the altered bank geometry simulating re-grading, all methods considered for the program which could be modeled in BSTEM were found to be valid additions to the program. For example, when re-graded was simulated by increasing the bank geometry slope by a factor of 3 and adding the allowable shear stress of 120 Pa for a live stake protection, it was found that the ending bank factor of safety for the hypothetical month of storms increased from 1.21 to 13.1, and instead of there being 18 failures in a month, there were now none. The eroded profiles for these two simulations are shown below in Figure 5. Final bank factors of safety and number of failures during the hypothetical month found for Site 27 with various protection strategies can be found in Table 6.

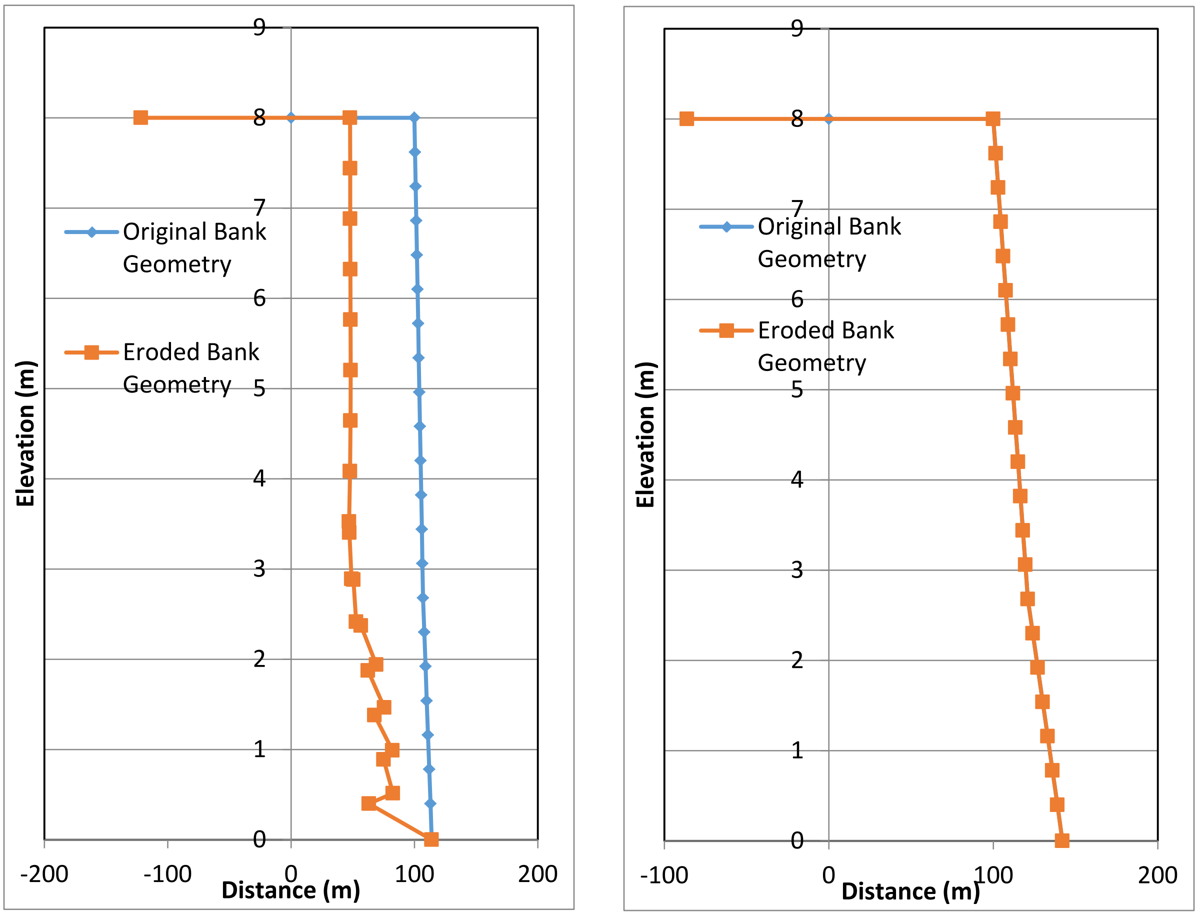

Figure 5: BSTEM final eroded profiles with no protection (right) and with the added protection of live stakes (left).

Table 6: BSTEM final results for Site 27 with various protections.

Site 27				
Protection	**None**	**Joint Planting**	**Live Fascines**	**Brush Layering**
Final Bank Factor of Safety	1.21	5.37	5.37	4.76
# of Failures	18	0	0	0
Critical Shear Stress (Pa)	0.3	120	72	19

Conclusion

Environmental, Societal or Global Impacts

The primary positive impact of this solution is to prolong the life of John Redmond Reservoir by reducing sediment loads in the Neosho River and thus helping the lake to retain its volume. This is important to society because the reservoir is a drinking water reservoir that is used for domestic public (drinking) water and cooling water for a nuclear power plant and, in addition, streambank stabilization will mitigate other negative side effects of sedimentation. Streambank stabilization also provides the environmental benefit of gentler banks and vegetation providing better wildlife habitat, which is particularly important on streambanks in a wildlife preserve. Furthermore, this design provides a model from which to develop similar programs in other watersheds, which could then put into effect the same positive impacts in many other regions.

Further Development

There are several areas in which this program can still be improved. In addition to spending more time to refine the style, look, and user interface of the program itself, it would be useful to conduct the same watershed characterization at other regions in the Neosho Headwaters Watershed beyond the small focus of the priority sites in the Flint Hills National Wildlife Refuge identified by the Kansas Water Office. This would enable the USACE to determine whether the program is truly applicable on a watershed scale. In addition, efforts might be made to create a template based on this design in order to create streambank stabilization method selection programs specific to endangered watersheds in many other regions.

Appendix A: Works Cited and Consulted

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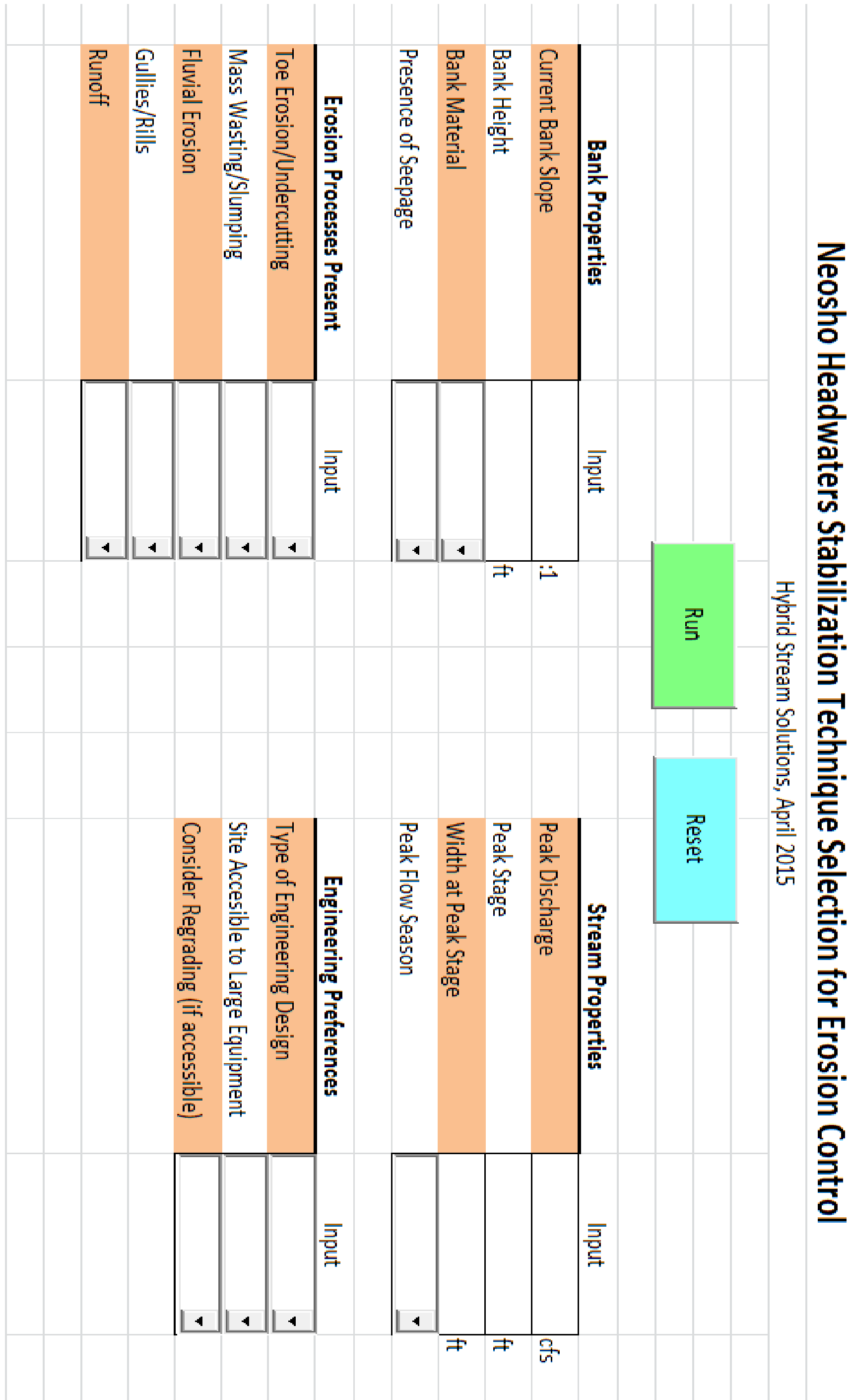
Appendix B: Method Selection Program



“Input” Worksheet

RECOMMENDATIONS	#1	#2	#3
Specifications			
Stabilized Erosion Processes			
Location on bank			
Required Slope			
Regrading			
Allowable Velocity			
Allowable Shear Stress			
Improves drainage/Limits seepage			
Complexity/Intensity			
Combined with structural methods			
Environmental Benefits			
Limitations			
Best Season for Installation			
Best Materials for Installation			
Costs			
Estimated Costs per Linear Foot of Bank Length			
Estimated Time for Installation			
Maintenance Required			

“Output Matrix” Worksheet

Appendix C: Soils Data Graphs

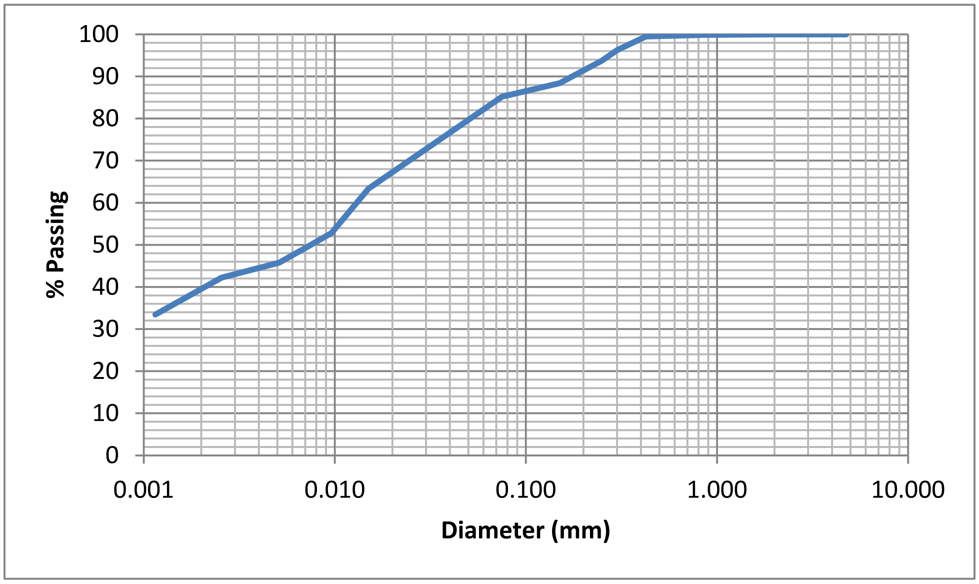


Figure C-1: Particle Size Distribution (Site 27 – clay)

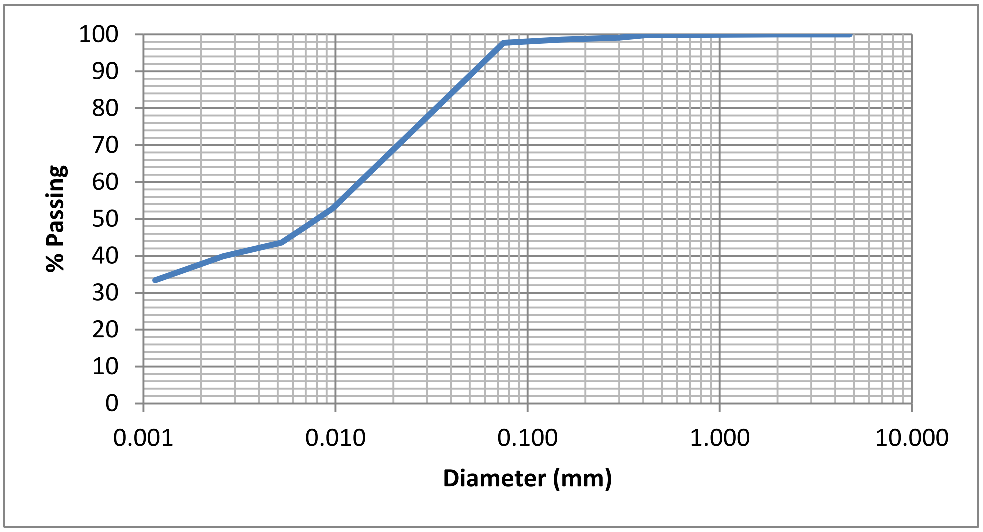


Figure C-2: Particle Size Distribution (Site 28 – silty clay)

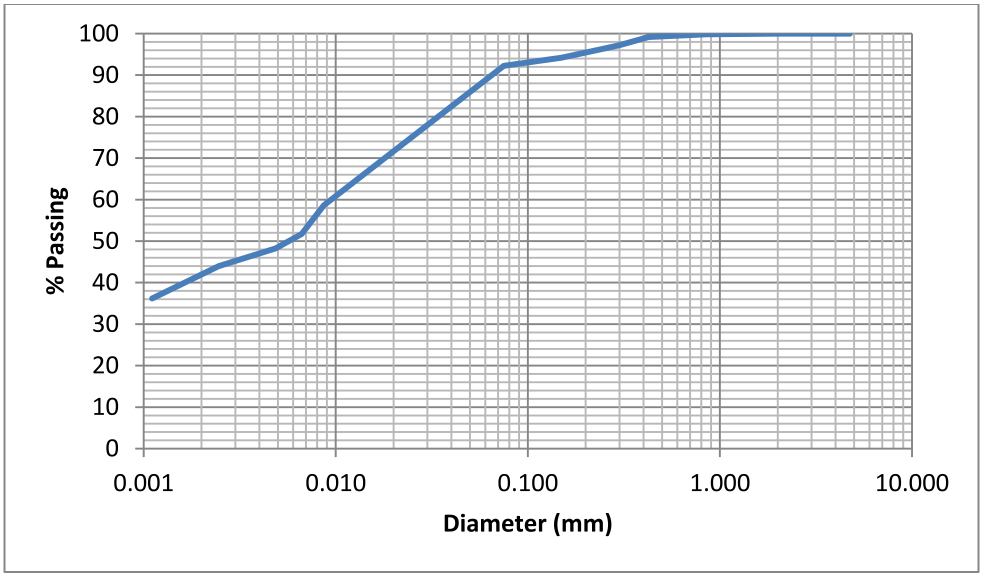


Figure C-3: Particle Size Distribution (Site 30 – clay)

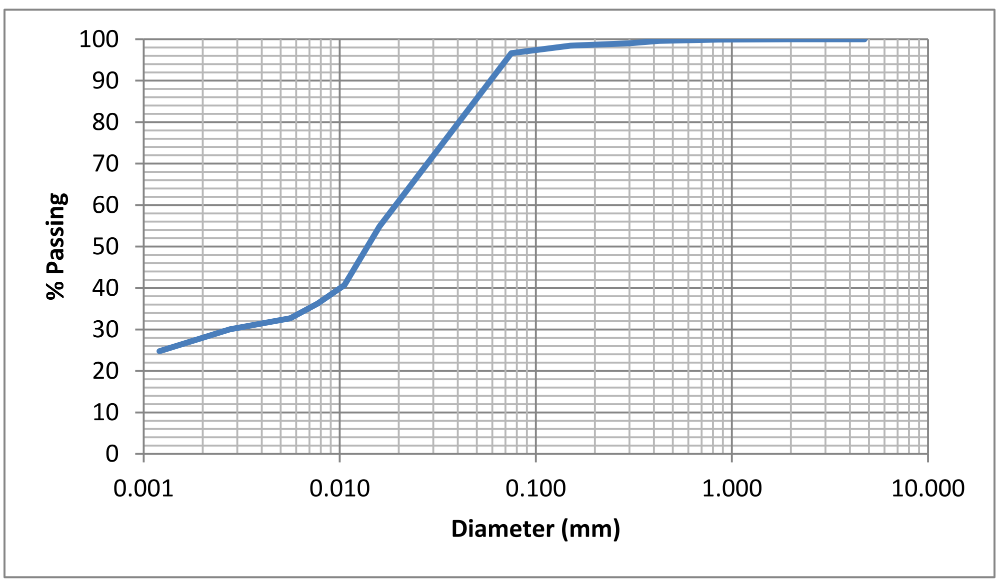


Figure C-4: Particle Size Distribution (Site 33 – silty clay loam)

Appendix D: Literature Review

This section details journal articles, research projects, patents and other documents needed to progress with the project. These include documents intended to guide testing, modeling and evaluation of the problem as well as methods to remediate the problem.

Methods of Streambank Stabilization

Before the major categories and specific methods of streambank stabilization are discussed, it must be mentioned that not all of these methods serve the same purpose. Some common methods of streambank stabilization focus only on protecting either the top or the bottom portion of the bank. Other methods focus on reducing or filtering runoff before it enters the stream, which is not the most direct approach to solving our objective. In any case, the descriptions of each method or category of methods which we have found relevant will include the scope or purpose of each method.

Streambank Re-grading

In many cases in which a stream has been undercut (the “toe” or bottom part of the stream has been eroded away) or incised (in which erosion has caused sloped banks to become vertical or near-vertical), movement of the bank material is often necessary. As seen in Figure D-1, a sloped bank can then be re-created based on analysis of the stability of the native material at the site. Depending on how the work is done (usually with construction machinery), this process can be more or less intensive, but is generally considered low-cost. It is sometimes, though rarely, used as a method unto itself. In many cases, however, in order to protect the bank once re-graded, this method is used only as a “first step” (TVA, 2014).

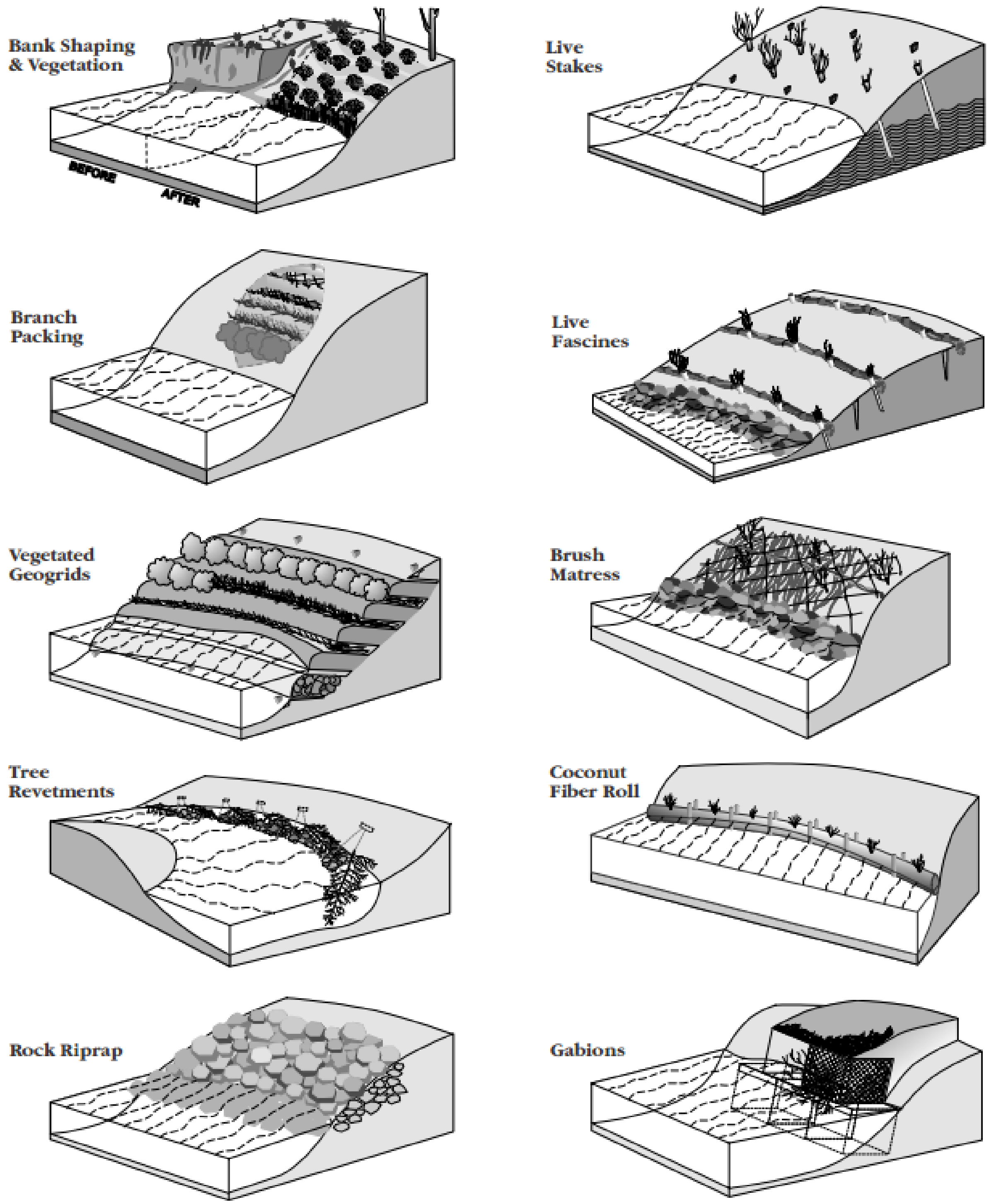


Figure D-1: Basic cross-section figures of several different methods of streambank stabilization (TVA, 2014).

Biological Streambank Stabilization/Restoration

It is accepted among the stream conservation community that plant roots are one of the best ways to keep bank material (soil) in place. These methods are also highly desirable because of their friendliness to the stream ecosystem. They are almost always implemented with the hope that after a certain period of time, the bank will be healthy, stable, and accepting of native natural life.

Vegetation Alone

Fully grown or well-developed trees, shrubs, and other plants are planted directly onto re-graded banks. While this method is inexpensive and only moderately labor-intensive, it is risky if used alone, as flooding or high flow events can easily rip plants from the bank if they do not have well-established roots at that time (TVA, 2014).

Live Stakes/Whips/Spiling

A live stake is a living but dormant cutting of a woody plant which is placed (staked) into the streambank. The vegetation can then put down roots. Live stakes can be used alone or to hold other stabilization materials in place, as shown in Figure D-2. Live whips are similar but much thinner and longer, and used more often for banks with normal high water content. Since stakes and whips often grow into trees and shrubs, they are used to protect the upper slope of a bank. They are inexpensive and not labor-intensive (Anstead and Boar, 2011).

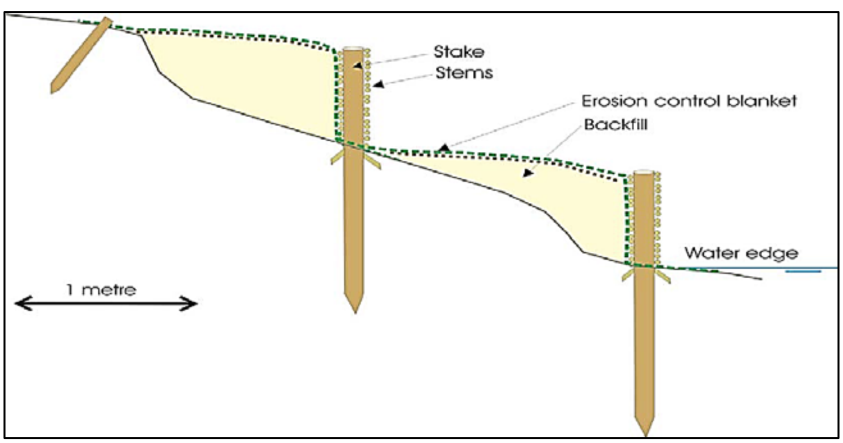


Figure D-2: Live stakes (Anstead and Boar, 2010).

Joint Plantings

A joint planting system complements the use of live stakes by protecting the toe of the bank. Rock is laid down on the bank, and live stakes or similar woody material placed in the "joints" between the rocks, as can be seen in Figure D-3. Eventually, once the vegetation becomes large and established enough, the rocks might be removed. Because of the use of rock and the long-term maintenance requirements, this method is moderately expensive and labor-intensive. The vegetated gabion method does essentially the same thing, but using gabions
rather than riprap (Sotir and Fischenich, 2007).

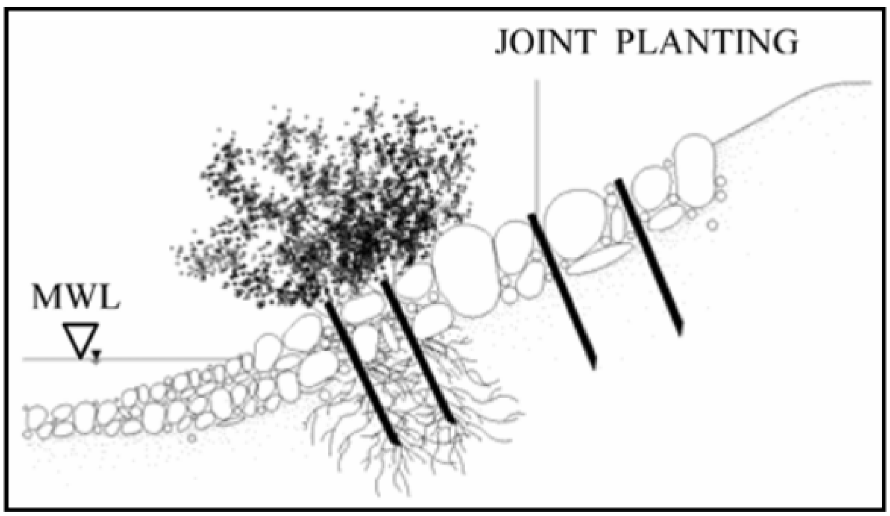


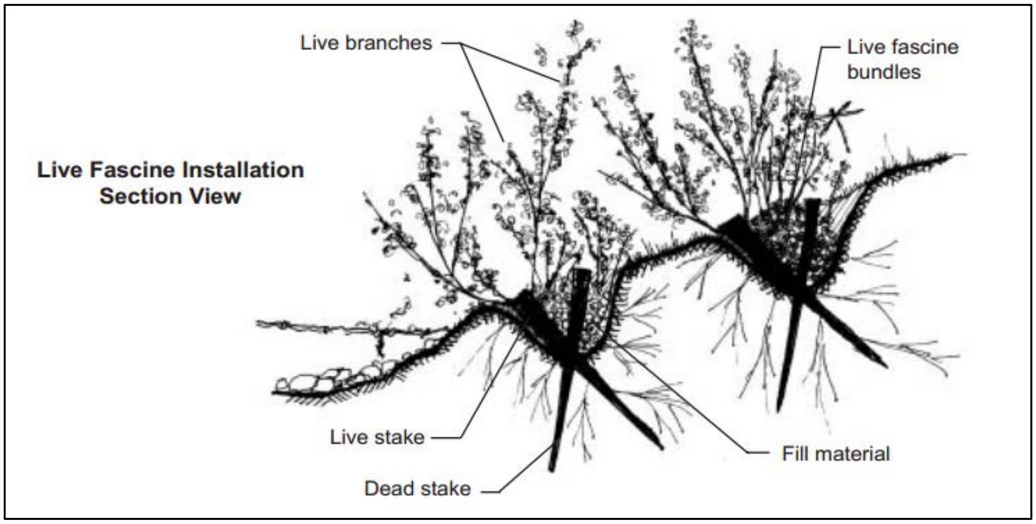
Figure D-3: A joint planting installation (Sotir and Fischenich, 2007).

Brush Layering

Long branches of woody materially are placed thickly on a slope and covered with soil until only a bit of the branch is visible. The soil-covered brush then acts as a foundation for the next layer in a series of terraces. This method is also not terribly expensive, but much more complex and time-consuming to construct (Lake and Dickerson, 2005).

Live Fascines

A fascine is a bundle of live branches, which are similar to but smaller than live stakes. They are placed vertically in shallow trenches in the sloped bank, which are then filled in with bank material. As shown in Figure D-4, they are secured with dead woody stakes to prevent them from being carried away in high flow events. They are inexpensive and fairly low in labor requirements, and protect the upper part of a bank. The branch packing method does much the same thing, but is used specifically to fill holes or gullies in banks, especially if re-grading may



not be necessary (FISRWG, 1998).

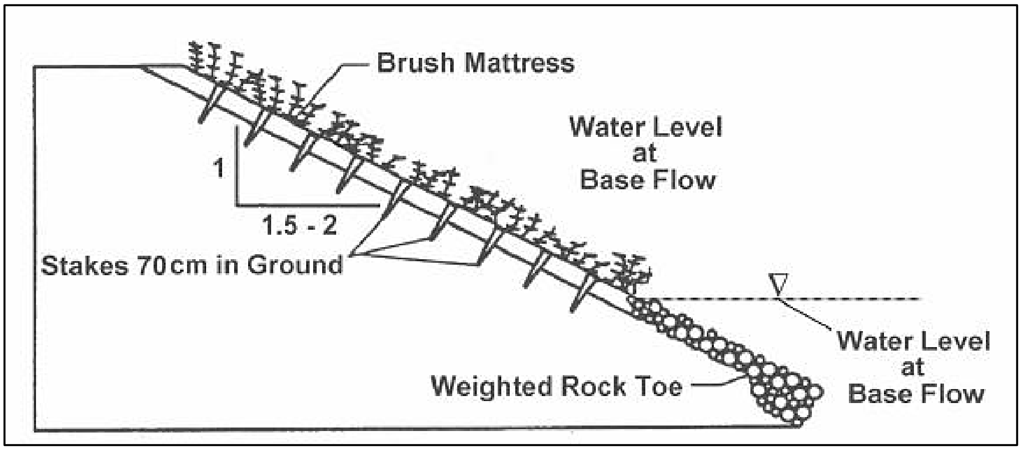
Figure D-4: Live fascines (FISRWG, 1998).

Vegetated Geogrids

These work much the same as a joint planting or vegetated gabion, but instead of rocks, the stakes are inserted between clumps of compacted soil encased in geotextile material. An advantage of this method is that labor-intensive maintenance is not needed later to remove the rocks. This method may also be used in any portion of the back, near or away from the water line. However, this is a very expensive method (Geosyntec Consultants, 2006). See Figure D-1 on page D-2.

Brush Mattress

Woody material is layered horizontally along a streambank and held in place by live stakes (or metal stakes, and possibly wire). This mattress protects small seedling trees and brush, as well as seed plantings, from being washed away by storm runoff or high flows. It is understood that this is only viable for the upper bank and a very secure method such as riprap is often used to protect the toe and keep the mattress from being carried away. Figure D-5 shows a brush mattress treatment applied in conjunction with a weighted rock toe. It is moderately expensive and complex option that works extremely well under a specific set of circumstances such as sunny locations with perennial stream flow and a moderate percentage



of clay in the soil for stake anchoring (Allen, 2001).

Figure D-5: Profile view of brush mattress with rock toe (Allen and Fischenich, 2001).

Tree Revetments

Cut trees are anchored along the toe of a streambank, as shown in Figure D-1 on page D-2. This method is low cost but labor-intensive, and must often be combined with a separate technique to protect the upper bank. Rather than simply holding soil in place, these cut trees also work to absorb high flow energy, "taking the blows" that might erode the soil (Streams for the Future, 2014).

Fiber Rolls

These work much like tree revetments, except that rolls of coconut hulls (see Figure D-6), other natural fibers such as straw, or synthetic fibers wrapped in a close netting or loose-weave cloth are placed at the bank toe to absorb flow energy. Though not exactly inexpensive, this method is less expensive than tree revetments and also less labor-intensive. Also like tree revetments, it is best when paired with another technique for the upper bank. However, it is only recommended for areas with constant flow (without common high flood events), as the roll is not as securely fastened to the bank (McClean, 2000).

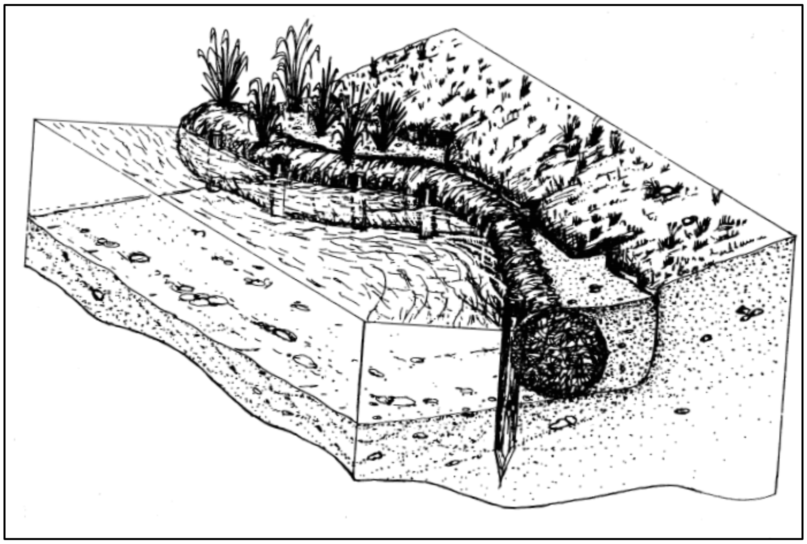


Figure D-6: Placement of coconut fiber rolls along the toe of a bank (McClean, 2000).

Structural Streambank Stabilization

Riprap

Riprap protects the toe of the bank much like its biological counterparts, the tree revetment and fiber roll, by absorbing flow energies and deflecting them away from the bank material. Riprap consists of hard, medium sized (human fist to head-sized) stones placed into the toe of the bank. Placing riprap is moderately expensive and labor-intensive, yet it is often paired with a biological upper bank protection mechanism. See Figure D-7.

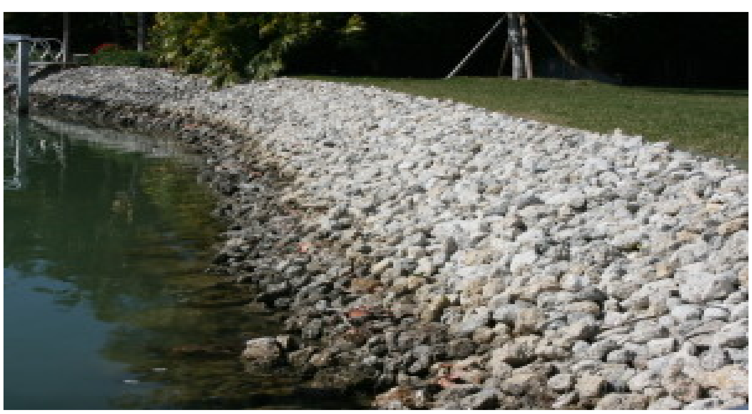


Figure D-7: Riprap along a coastal shoreline in Florida (Garland & Garland, 2014).

Gabions

Gabions are essentially riprap encased in wire baskets, which prevent the rocks from being carried away during floods. Though labor-intensive and very expensive, gabions also eliminate the need for bank re-grading because they can be placed vertically. See Figure D-8.

Figure D-8: Gabions along an English streambank (Gabion Erosion Control, 2014).

Concrete

Lining the stream walls with concrete prevents the water from ever reaching the soil, thus eliminating erosion risk from the stream itself. This is a very expensive and complex process, but one which eliminates the need for bank re-grading.

Rock Vanes

These methods disperse water energy by redirecting towards the center of the stream by means of large boulders placed in the stream itself. This is a method of high cost and moderate labor intensity. Specific types of rock vanes include j-hooks, cross vanes, and w-vanes (Brannaka, 2005).

Summary of Methods

These approaches toward achieving streambank stabilization represent a wide range of solutions which offers our team a broad spectrum of ideas to further analyze. Many of the presented methods are accompanied by drawbacks, but they provide our team with foundational information for developing a recommendation matrix spreadsheet. Table D-1 qualitatively summarizes the aforementioned treatments.

Table D-1: Basic outline of methods and qualities of each possible method.

Method	Protects		Combinations Possible	Complexity	Labor Intensity	Cost	Maintenance
	Upper Bank	Toe					
streambank re-grading	x	x	yes; necessary	low	moderate	low	low
vegetation	x	x	yes; necessary	variable	low	low	moderate
live stakes	x		yes	low	low	low	low
joint planting	x	x	yes	moderate	high	high	high
brush layering	x		limited	moderate	moderate	moderate	low
live fascines	x		yes	moderate	low	low	very low
vegetated geogrids	x		limited	high	high	high	very low
brush mattress	x	x	yes	moderate	moderate	moderate	moderate
tree revetments		x	yes	moderate	moderate	moderate	high
fiber rolls		x	yes	low	variable	variable	high
vegetated gabions	x	x	limited	moderate	high	high	high
rock vanes		x	yes	moderate	high	high	low
erosion control blanket	x		yes	low	moderate	variable	low

Appendix E: BSTEM Technical Information

The vertical failure analysis uses a slicing method which is visually demonstrated in Figure E-1. The vertical forces—gravity and the vertical portion of the normal force—acting on each of the sub-slices are summed to determine the normal force acting on each composite slice. The horizontal forces acting on each composite slice are summed to calculate the inter-slice normal force. Inter-slice shear force is accounted for by a method programmed into BSTEM. The bank factor of safety concerning vertical failure is calculated by balancing the horizontal and vertical forces of each sub-slice and the horizontal forces for the entire bank (Langendoen, 2013).

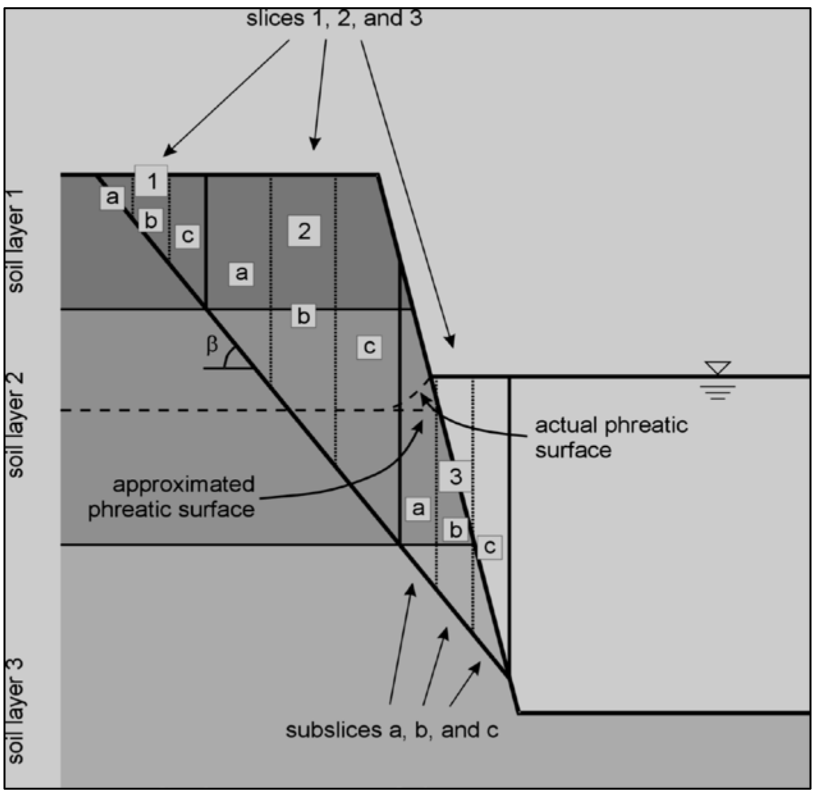


Figure E-1: Example of the vertical failure analysis (Langendoen, 2013).

The cantilever shear failure algorithm calculates the bank factor of safety by dividing the shear strength of the soil to the weight of the cantilever. A variable is included in calculating the factor of safety for this method that correctly represents the effect of the water on the weight of the soil (Langendoen, 2013).

As for the toe erosion portion of BSTEM, the average applied boundary shear stress, maximum lateral retreat and total eroded area are calculated internally; they are calculated in the process of each simulation. Due to the fact that the typical equation for calculating boundary shear stress does not account for curvature, but this again is calculated internally within BSTEM. In addition—similar to the bank stability portion of BSTEM—based on the inputs, eroded profile and initial profile are graphically represented and compared against each other on the same graph (Langendoen, 2013).

April 30, 2015

Neosho Headwaters Streambank Stabilization Selection

Presented by:
Hybrid Stream Solutions
Emelia Brooks, Lizzie Hickman
Leslie Ogar

Prepared for the USACE Tulsa District

Outline

Final Deliverable: Automated Selection Program

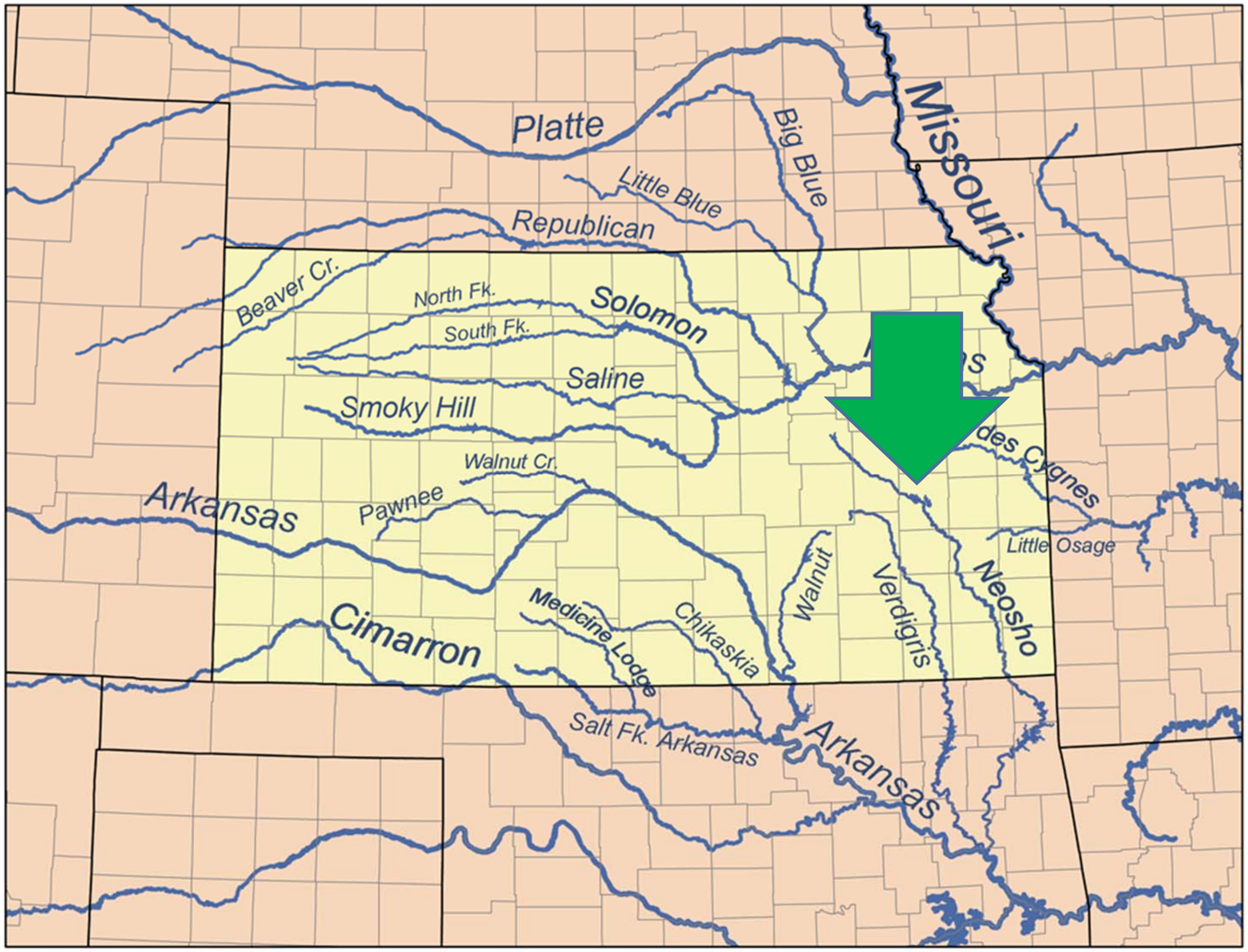
- Introduction
- Literature Review: Streambank Stabilization Methods
- Design Approach
- Watershed Characterization
- Selection of Methods
- Validation of Method Selection
- Conclusion

USACE – Tulsa District

(www.swd.usace.army.mil)

- Established 1939
- 1 of 4 Districts in Southwest Division
- Services
  - Southern Kansas
  - Northern Texas
  - All of Oklahoma

Introduction



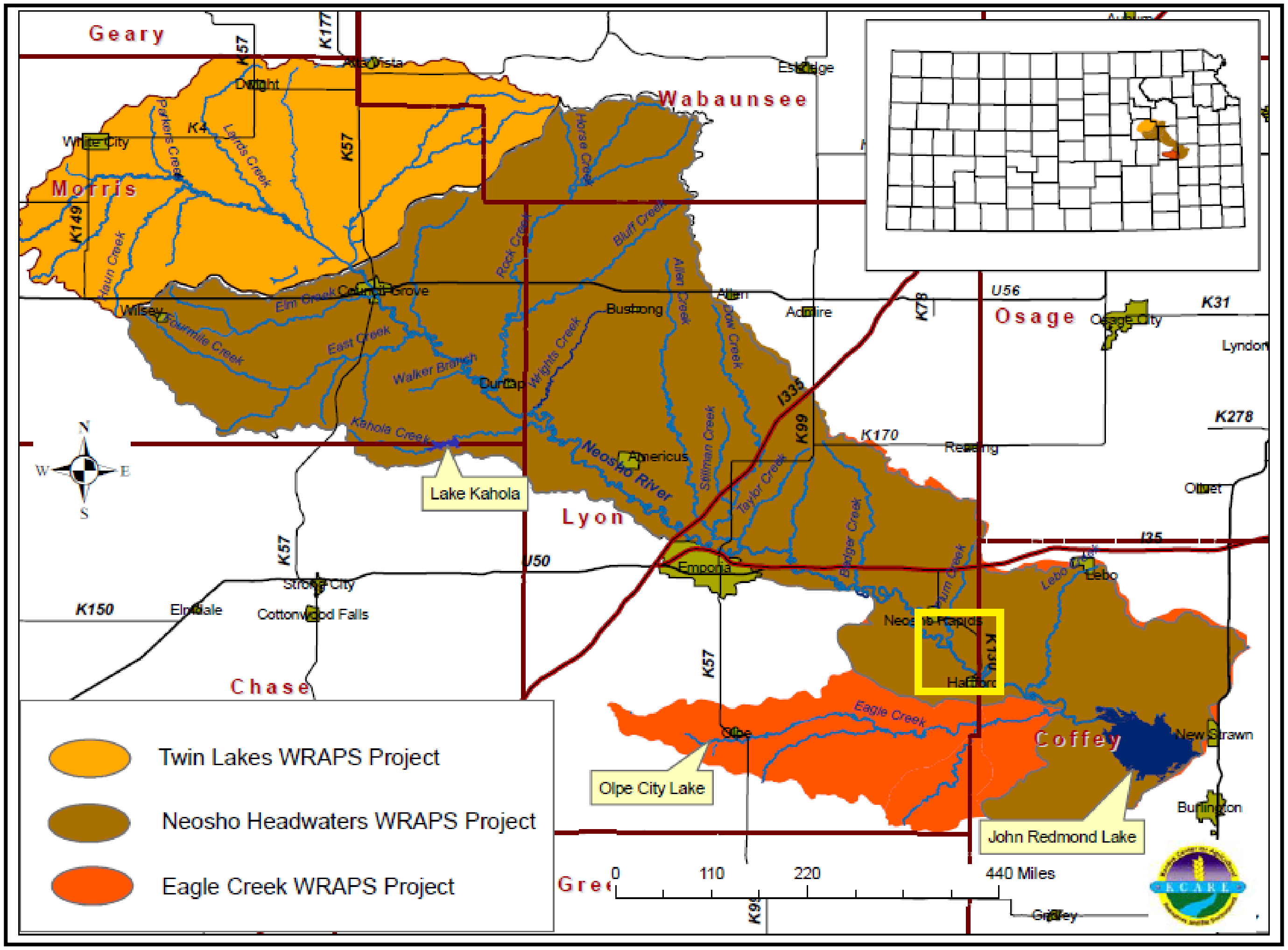
Map of Kansas Waterways (Kmusser, 2007)

John Redmond Reservoir

Map of John Redmond Reservoir (Google, 2015)

- Storage capacity
  - Original: 82,000 ac-ft
  - Current: 46,000 ac-ft
- Storage reduction
  - 52%
- Sedimentation rate
  - 738 ac-ft/yr
- Dredging in 2015

Introduction



Map of Neosho Headwaters Watershed (KCARE and KSRE, 2010)

Neosho Headwaters

- Sediment Total Maximum Daily Load
  - 59,100 tons/yr set by KDHE
  - 29,760 tons/yr over capacity, in 2010
  - Majority of sediment is from eroding streambanks
- 32 Priority sites identified by the KWO
- Requires 0.75 tons/ft of bank/yr reduction from each priority site

Problem Statement

Create watershed-specific guidelines for innovative, cost-effective designs to most effectively reduce sedimentation, thus prolonging the life of John Redmond Reservoir.

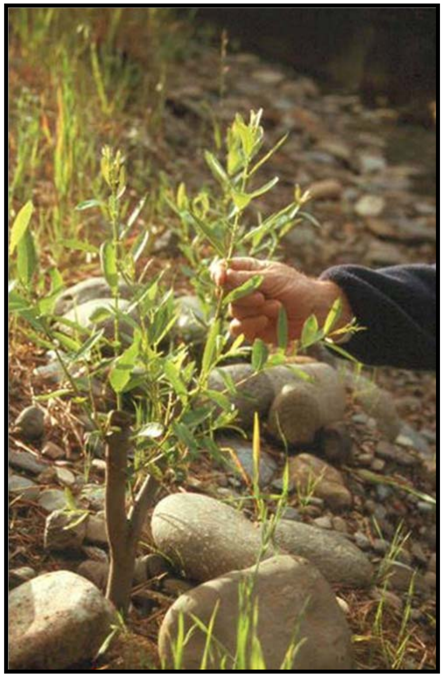
Customer Requirements

- Federal land
- Federal regulations
- Guidance Document
- Cost/Benefit Analysis

Conclusion: Addressing the problem of upstream bank failure is the most direct way to reduce sedimentation in John Redmond Reservoir.

Stabilization Techniques: Biological

- Vegetation alone
- Live Staking
  - Willow Stakes
- Brush Layering
- Vegetated Geogrids
- Brush Mattressing



Growth of Live Stakes (TRB, 2004)

Stabilization Techniques: Structural

Gabions (Gabion Erosion Control, 2014)

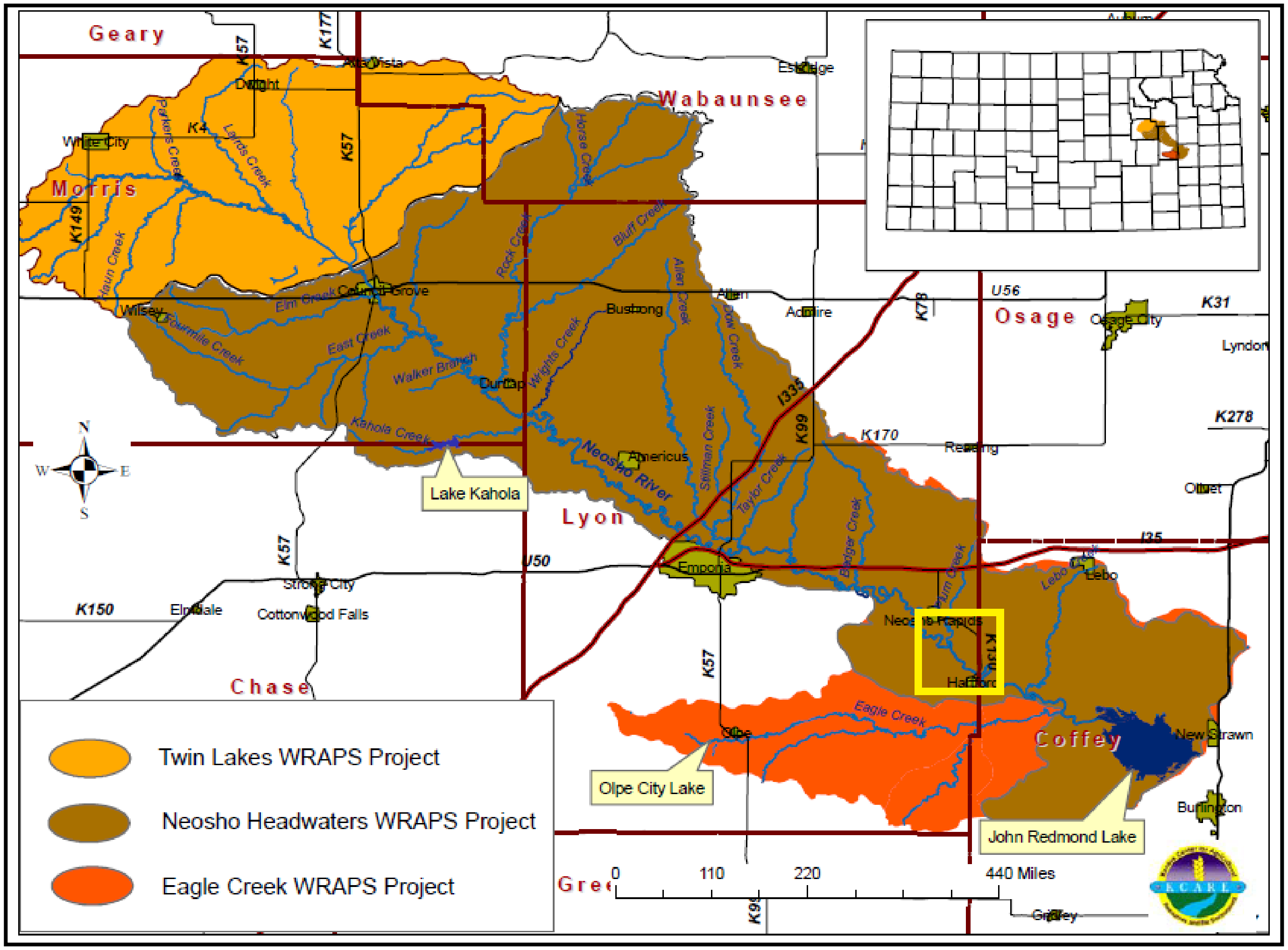
- Riprap
- Gabions
- In-Stream Toe Protection
- Seawalls

Stabilization Techniques: Combination

- Joint Planting
- Vegetated Gabions
- Upper Bank + Toe Protection

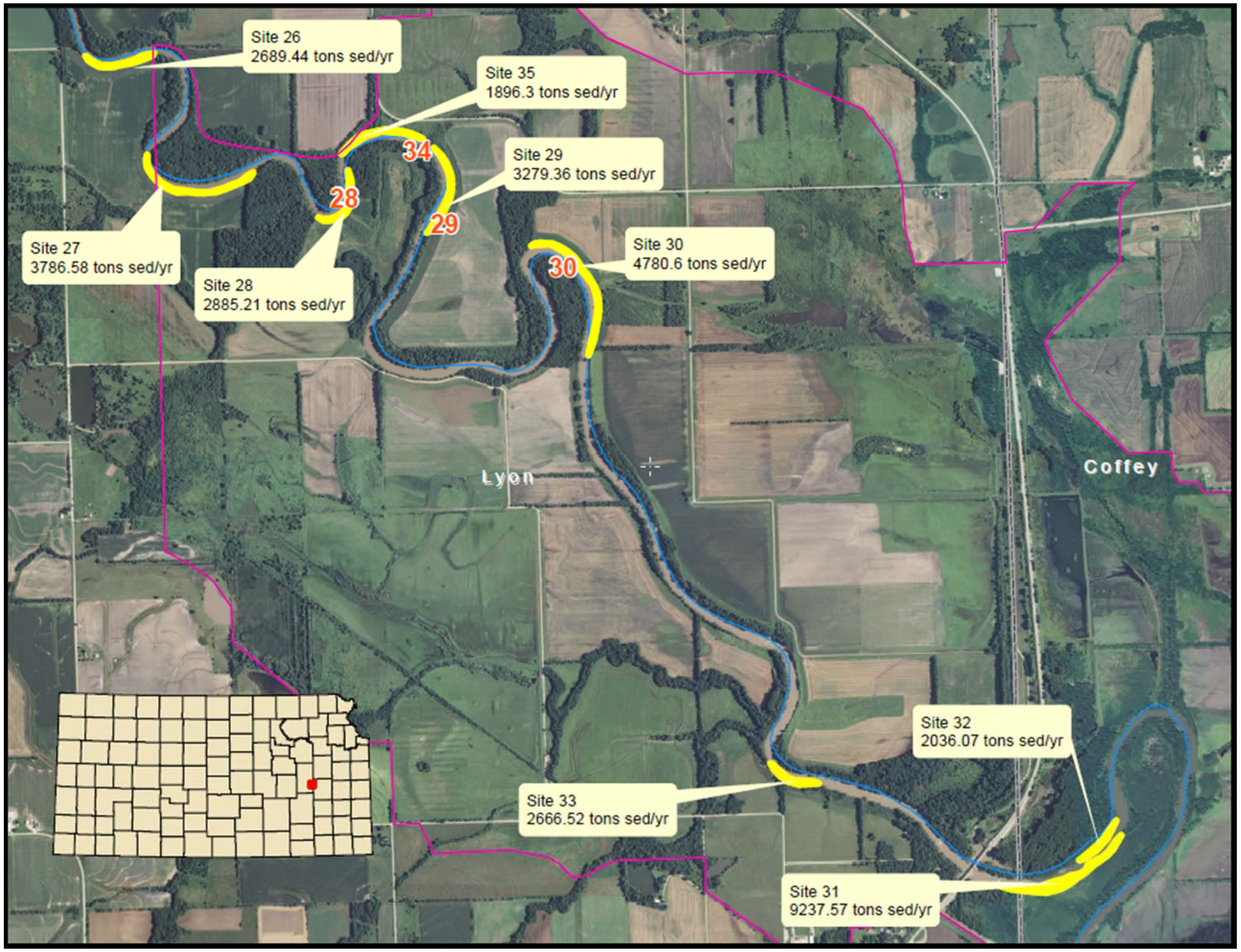
Vegetated Gabion Baskets (TRB, 2004)

Design Approach



Map of Neosho Headwaters Watershed (KCARE and KSRE, 2010)

Design Approach



Map of Priority Sites in Flint Hills National Wildlife Preserve (KWO, 2014)

Initial Approaches

- 1st Approach - pick top site(s)
  - Specific design with detailed manual
  - Less innovative and effective
- 2nd Approach – characterize sites
  - Develop a matrix of methods
  - Compare benefits and costs
  - More effective, still not innovative enough

Why not automate it?

Final Design: Excel Program

- General characterization of sites
- Applicable to entire watershed
- Automated selection process
  - Saves time and can be modified

Final Deliverables

- Macro-enable Excel program
- Detailed guideline document

Design Approach

Selection Program

Neosho Headwaters Stabilization Technique Selection for Erosion Control

Hybrid Stream Solutions, April 2015

Run | Reset

Bank Properties	Input		Stream Properties	Input	
Current Bank Slope		:1	Peak Discharge		cfs
Bank Height		ft	Peak Stage		ft
Bank Material			Width at Peak Stage		ft
Presence of Seepage			Peak Flow Season		

Erosion Processes Present	Input	Engineering Preferences	Input
Toe Erosion/Undercutting		Type of Engineering Design	
Mass Wasting/Slumping		Site Accesible to Large Equipment	
Fluvial Erosion		Consider Regrading (if accessible)	
Gullies/Rills			
Runoff			

User Input Worksheet of Method Selection Program

Selection Program

Bank Properties	Input	
Current Bank Slope		:1
Bank Height		ft
Bank Material		
Presence of Seepage		

Erosion Processes Present	Input
Toe Erosion/Undercutting	
Mass Wasting/Slumping	
Fluvial Erosion	
Gullies/Rills	
Runoff	

User Input Worksheet of Method Selection Program

Selection Program

	Stream Properties	Input	
	Peak Discharge		cfs
	Peak Stage		ft
	Width at Peak Stage		ft
	Peak Flow Season		
	Engineering Preferences	Input	
	Type of Engineering Design		
	Site Accesible to Large Equipment		
	Consider Regrading (if accessible)		

User Input Worksheet of Method Selection Program

Selection Program

Neosho Headwaters Stabilization Technique Selection for Erosion Control

RECOMMENDATIONS	#1	#2	#3
Specifications			
Stabilized Erosion Processes			
Location on bank			
Required Slope			
Regrading			
Allowable Velocity			
Allowable Shear Stress			
Inproves drainage/Limits seepage			
Complexity			
Intensity			
Environmental Benefits			
Limitations			
Best Season for Installation			
Best Materials for Installation			
Costs			
Monetary Costs			
Time for Installation			
Maintenance Required			

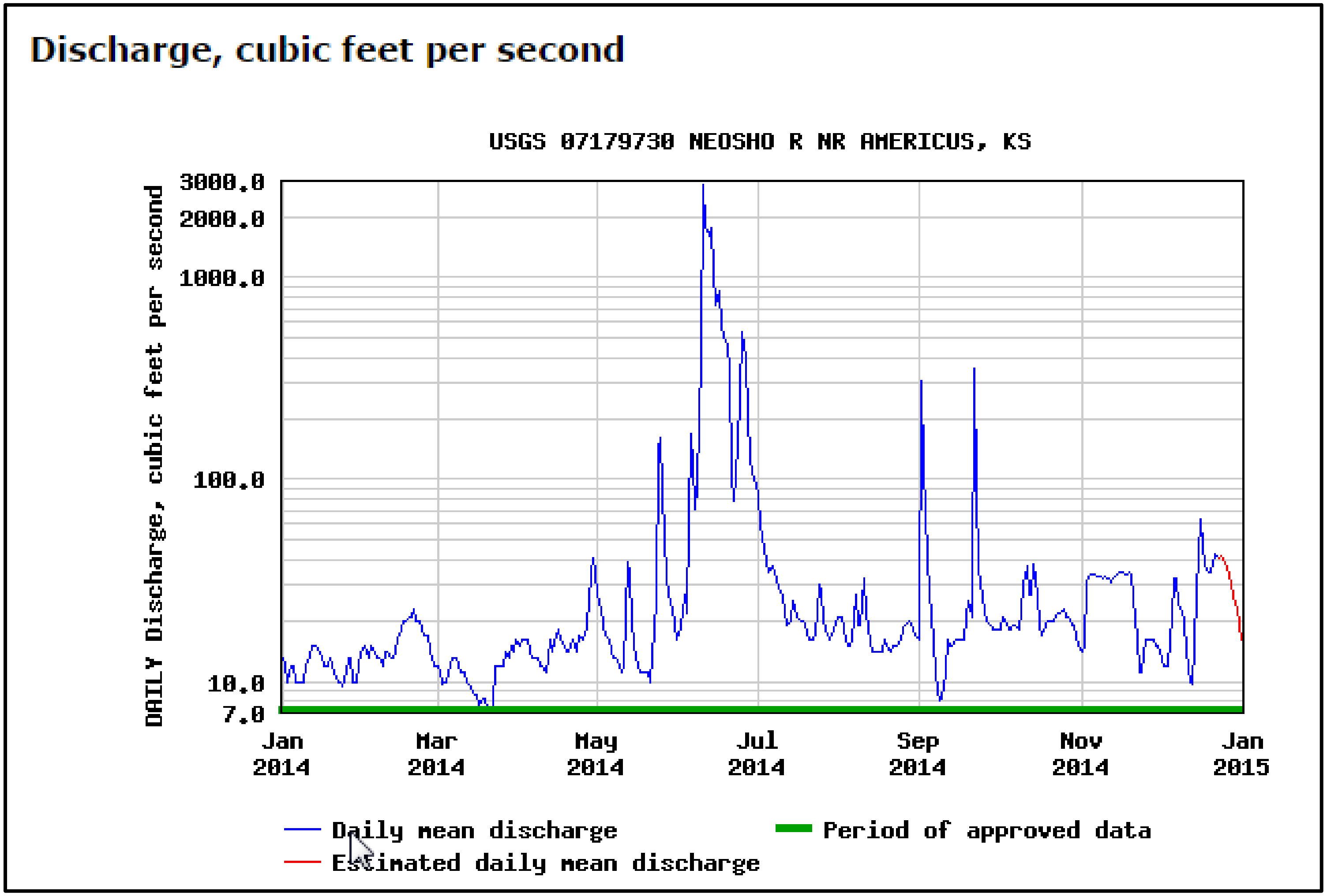
Automated Output Worksheet of Method Selection Program

Guidance Document

Priority Site 30

- Examples of program use
- Chosen case study priority sites
- More detailed description plus cost/benefit analysis

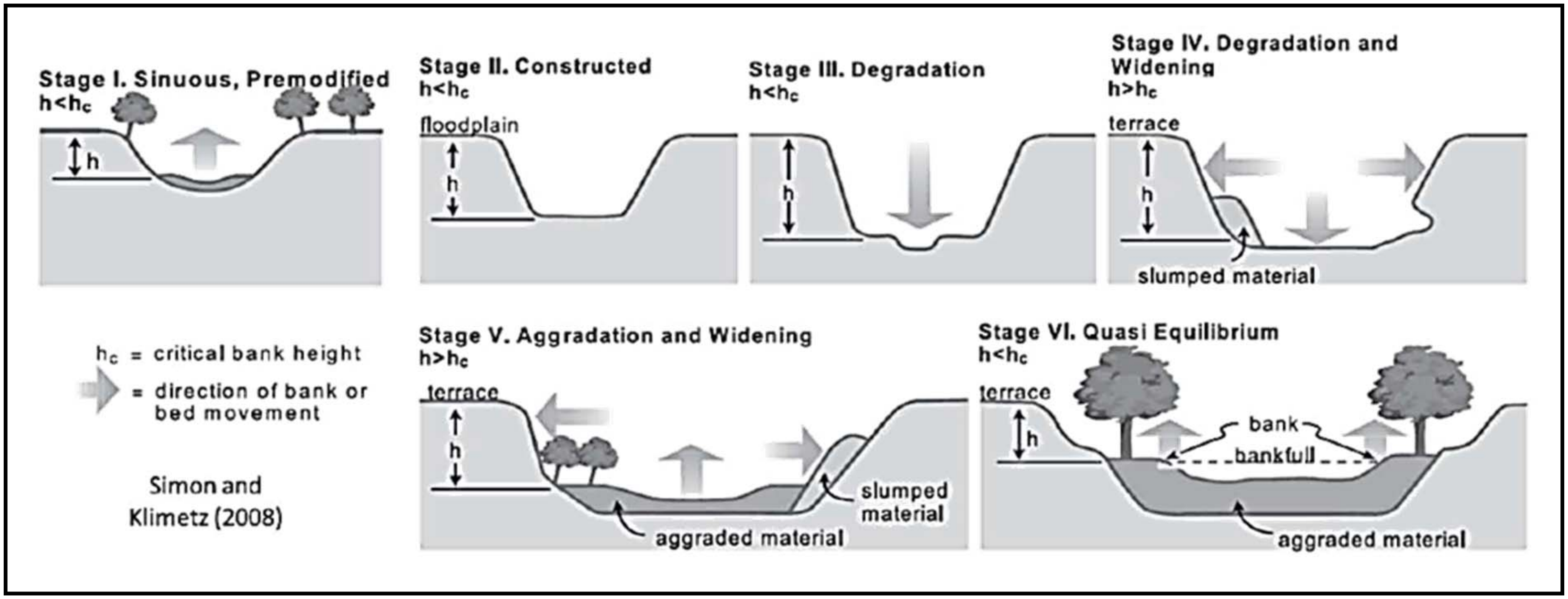
Characterization



Daily Discharge 2014: USGS Americus Gage

Data Collection

Site Evaluation



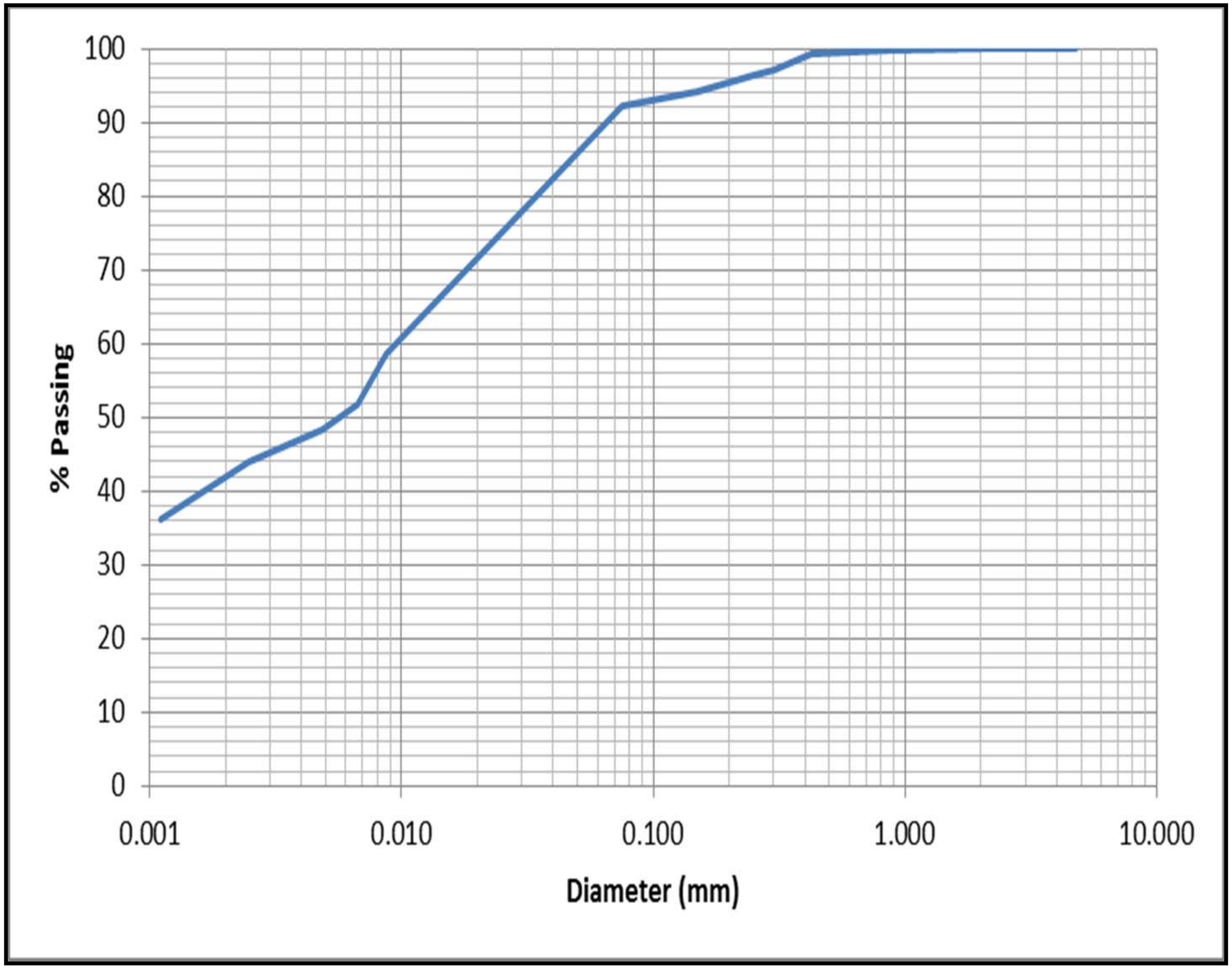
Stage of Channel Evolution

Soil Characterization

- Soil surveys
- Field soil sampling
- Full particle size distribution analysis
- Large amounts of clay present

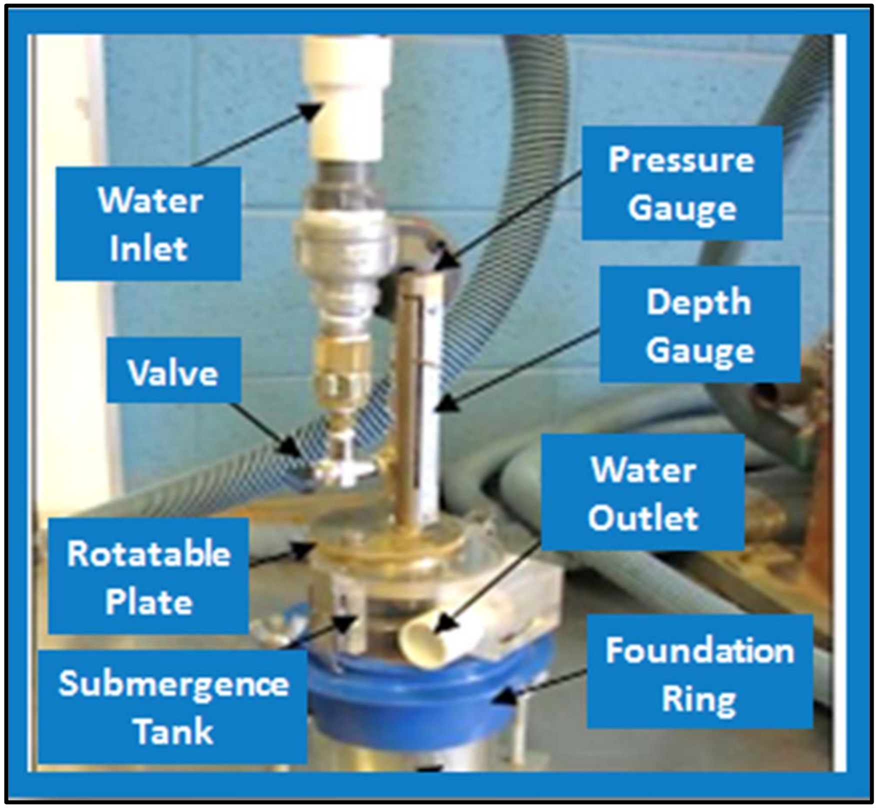
Site #	Soil Type
27	clay
28	silty clay
30	clay
33	silty clay loam

Characterization



Particle Size Distribution: Site 30

Jet Erosion Testing



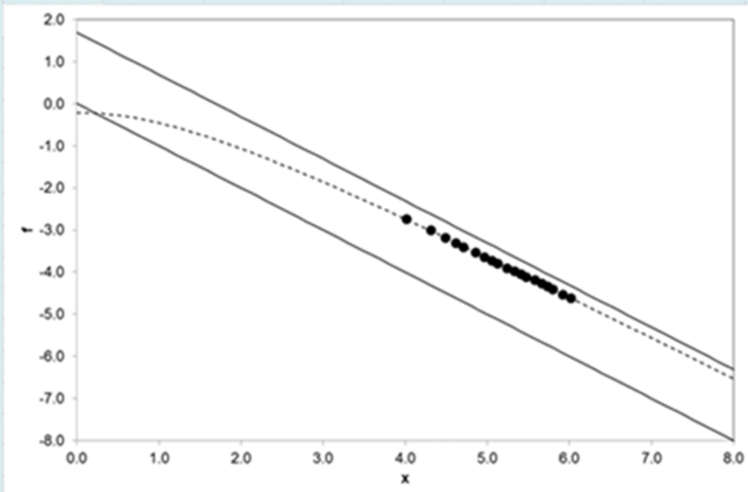
JET Apparatus Diagram

Jet Erosion Test

JET Results

Blaisdell Solution

τ_c (Pa)	0.31
kd (cm^3/N·s)	33.03



Site	τ_c (Pa)	kd (cm^3/Ns)
Blaisdell Solution		
27	0.31	33
28	0.12	46
30	0.08	115
33	0.52	22
Scour Depth Solution		
27	1.3	242
28	0.86	220
30	0.7	610
33	1.6	156

Method Selection

Considerations

- Applicability to watershed
- Meets regulations
- Meets constraints

Some Exclusions

- Examples
  - Fiber Rolls
  - Erosion Blankets
- Method weighting

Bank Stability and Toe Erosion Model (BSTEM)

- Developed by USDA-ARS National Sedimentation Laboratory
- 70-90% of sedimentation from erosion of banks
- Need for model to quantify and simulate underlying erosion processes
- Available for download on USDA-ARS website

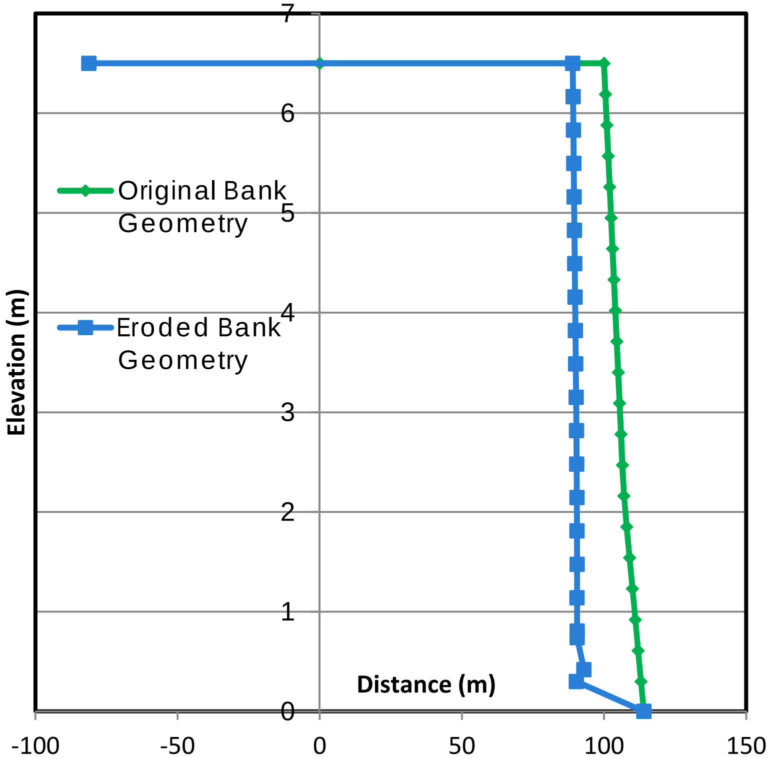
BSTEM Overview

- Simulates bank erosion over time
- Inputs:
  - Original bank profile
  - Bank material (soil) parameters
  - Hydrograph (stream stage over time)
- Outputs:
  - Bank factor of safety with time
  - Eroded bank profile

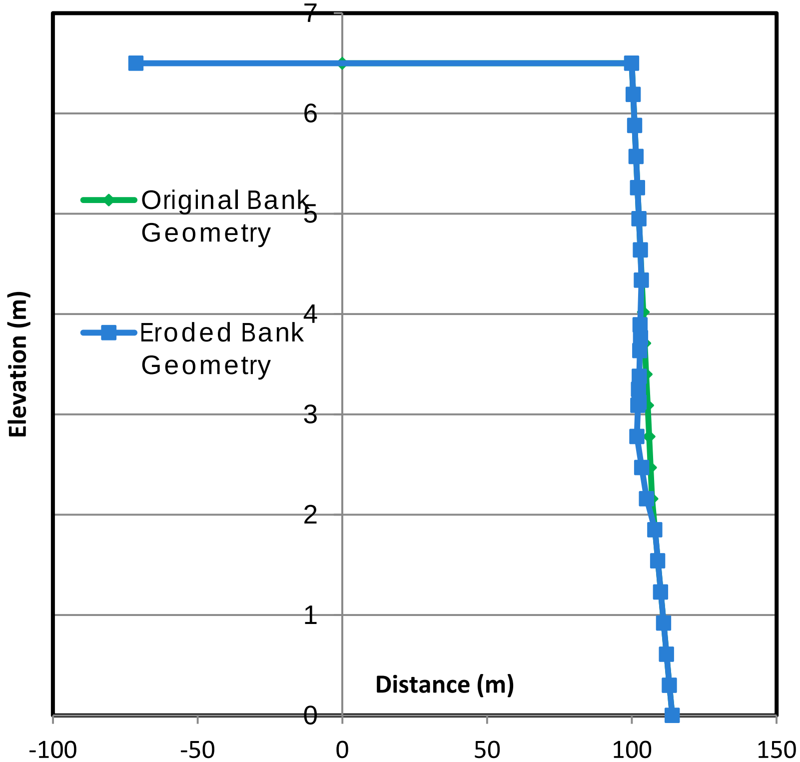
BSTEM and the Design

- Simulating a hypothetical storm
- Critical shear stress and erodibility coefficient from JETs
  - Other values are default for the soil type
- Comparing protected and unprotected banks

BSTEM Results

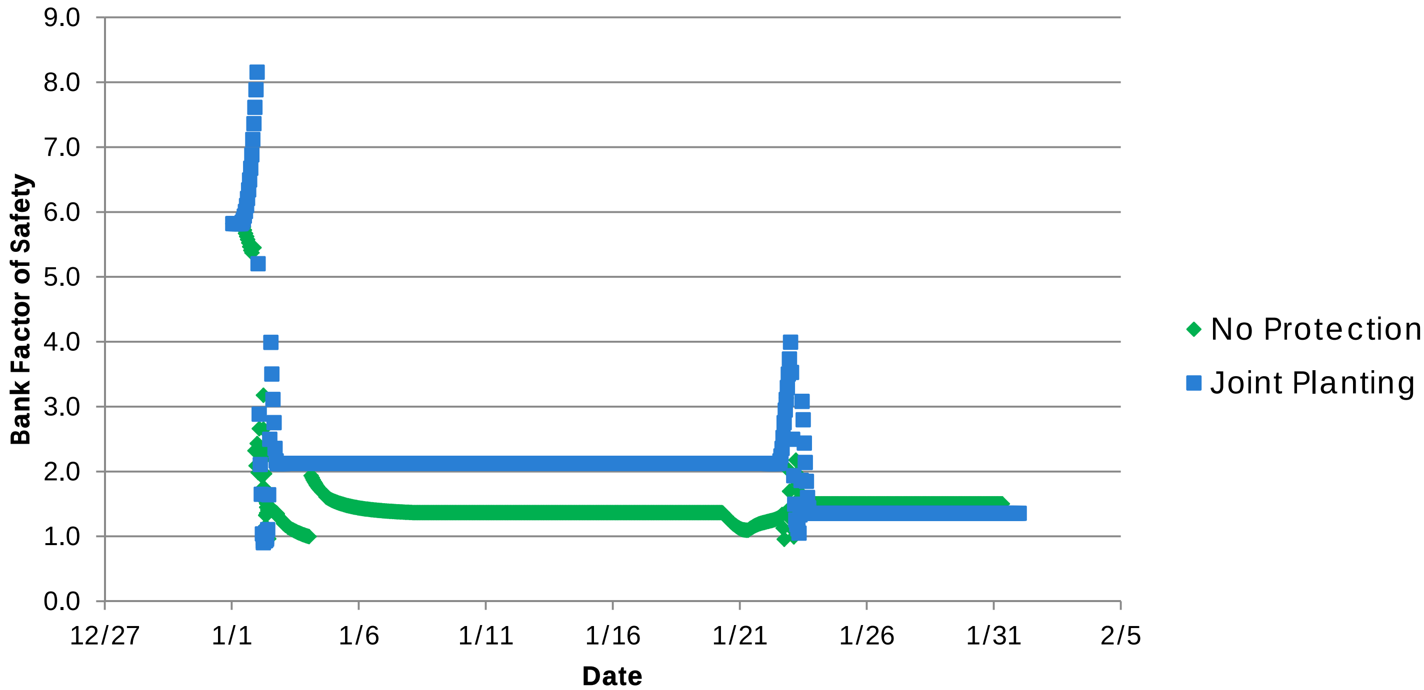


No Protection



Joint Planting

BSTEM Results



Design Impacts

- Prolong the life a drinking water reservoir
- Create and maintain habitat for wildlife
- Template for other watersheds

Newly Restored Streambank (TRB, 2004)

Further Development

- Refine user interface
- Case studies/test program applicability outside priority sites
- Create outline to develop similar programs in other watersheds

Conclusion

- Recommendation program suggests options to optimize sedimentation reduction
- Guidance document gives explanations and general instructions

Acknowledgements

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- Susan Metzger, Kansas Water Office

Message from Our Client

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Questions?

Hybrid Stream Solutions

Streambank Management

Design Proposal Report:

Streambank Stabilization on the Neosho River for Sedimentation Reduction in John Redmond Reservoir

Emelia Brooks
Lizzie Hickman
Leslie Ogar

5 December 2014

Prepared for the US Army Corps of Engineers, Tulsa Office

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Introduction

John Redmond Reservoir, a drinking water supply reservoir in eastern Kansas on the Neosho River, has lost over 40% of its storage volume due to the settling of sediment carried in from eroding streambanks on the river itself. The US Army Corps of Engineers (USACE) Tulsa Office, has tasked Hybrid Stream Solutions with devising methods to reduce sediment loads in the Neosho River in order to prolong the life of John Redmond Reservoir in Kansas. Though the USACE is planning to dredge the reservoir in order to return it to its former capacity, it is crucial that this valuable freshwater source retains its full capacity in future years. The greatest source of these sediment loads in the river is erosion from streambanks in the Neosho Headwaters Watershed. Therefore, the best way to solve this problem is through stabilization of Neosho River streambanks against fluvial erosion and mass wasting.

This report contains detailed explanations of the problem; an overview of the general approach to solve the problem; descriptions of various current methods of streambank stabilization in practice; descriptions of research and testing needed to develop technical specifications for design guidance, as well as the preliminary results of that testing; a detailed description of proposed final deliverables and validation methods; and a proposed budget for second half of the project.

A complete list of references follows in the Appendices.

Problem Statement

Hybrid Stream Solutions' task is to create watershed-specific design guidelines for innovative, cost-effective designs to stabilize streambanks on federal land along the Neosho River, in the Neosho Headwaters Watershed, in order to most effectively reduce sedimentation in John Redmond Reservoir to prolong the life of the reservoir.

Statement of Work

This section details an overview of the general approach to the problem on the part of Hybrid Stream Solutions.

Scope of Work

The scope of work for this project includes: planning; bank restoration site selection; characterization of physical parameters of the stream and streambanks, both through literature and database review and physical and field testing done by the team; extensive literature review and analysis of streambank stabilization methods already in accepted use, including possible patent issues or opportunities; extensive review of federal (especially USACE) guidelines for streambank stabilization; creation of models or methods by which to judge the applicability of current methods to the sites in question; the design or modification of methods or combinations of methods, if necessary; and the physical testing and validation of optimum designs through the use of accurate scale models. Not included in the scope of this work is the actual restoration or construction of streambanks at the chosen priority stabilization sites on the Neosho River.

Period of Performance

The period of performance for the project began in September 2014 and will end on 30 April 2015. All tasks must be completed within this timeframe. Any large additional tasks or major expansions of project scope requested by the client to be completed by April 2015 must be approved by the Oklahoma State University BAE 4012/4023 instructor, Dr. Paul Weckler.

Place of Performance

Jet erosion tests, rapid geomorphic assessments, and soil sampling will take place onsite on Neosho River streambanks in the Flint Hills National Wildlife Refuge near Hartford, Kansas, in the Neosho Headwaters Watershed upstream of John Redmond Reservoir. The majority of work will take place in Stillwater, Oklahoma, using the resources of Oklahoma State University. Intensive computer modeling will take place in computer labs in the Biosystems and Agricultural Engineering (BAE) department. Any soil testing done with retrieved samples will be done in BAE laboratories. Any scale modeling and scale model testing performed later in the project will likely be done at the Stillwater USDA-ARS laboratory near Lake Carl Blackwell, though negotiations with their representatives for use of the space has not yet been initiated at this time.

Deliverables Schedule

A fully-revised, complete, and representative design guidance manual and a macro-enabled recommendation matrix are due the first week of May 2015. The manual will include detailed recommendations and specifications for installation, maintenance and cost for two to four of the most regionally optimum techniques recommended by the matrix. The matrix will consist of an input/output program for Microsoft Excel. Users will input known streambank characteristics and flow data, and the program will output a matrix of recommended treatments including the benefits and costs of each (including but not limited to effectiveness for the given bank, financial cost, time of installation, labor intensity of installation, and future maintenance requirements). It is understood that the purpose of all these methods will be, according to the given problem, reduction of sediment loads in the river.

Known Specifications

The planned streambank stabilization methods must be designed for streambanks on federal land in the Neosho Headwaters Watershed upstream of John Redmond Reservoir. The methods be designed to positively affect (reduce) the sediment load which enters the Neosho River from the streambanks, for the purpose of protecting the capacity of John Redmond Reservoir. Any plans for streambank restoration must be designed to adhere to any federal, state, and local regulations regarding construction and streambank management.

In addition, in order to reduce sediment load in the Neosho River from eroding streambanks, the methods recommended must be optimized for the particular stream-bank interaction system in the region in question. Characteristics under consideration include but may not be limited to characteristic 100-year peak flow of the particular reach of the Neosho River; bank soil types; typical bank soil moisture content; bank soil bulk density; bank soil erodibility factor; bank soil geotechnical strength (especially shear strength); and a Channel Stability Index for each site.

The Watershed Protection and Restoration Strategy (WRAPS) completed by the Kansas Center for Agriculture, Resources, and Environment (KCARE) along with Kansas State University in 2010 states that a sediment load reduction of 29,760 tons/year is needed to meet the sediment TMDL (total mass daily load) for John Redmond Reservoir, and adds that 3.50 tons/feet of bank length/year is being eroded from those streambanks which are designated Priority 1. It is also estimated in the document that a stabilization of all thirteen Priority 1 sites could result in a sediment load reduction of 49,704 tons/year, and that stabilization of all priority sites (from 3 priority rankings) could result in a sediment load reduction of 94,560 tons/year, thus meeting the TMDL for John Redmond Reservoir more than three times over. Assuming all 31 priority sites will eventually be restored or stabilized, however, this requires a minimum reduction of **960 tons/year (or about 0.75 tons/foot of bank length/year) from each site** in order for the John Redmond Reservoir TMDL to be met. At this time, this is considered a feasible goal due because, while it meets the TMDL, it is also much lower than the estimated sediment load reduction from stabilization of priority streambanks.

Work Breakdown Structure

The following is a hierarchal breakdown of work for our team in terms of objectives and deliverables, including tasks required for the completing of each set and subset.

1. **Neosho Headwaters Streambank Stabilization Guide:** This document will outline the problem presented by sediment loads in the Neosho River and emphasize the necessity of these methods with respect to the capacity of John Redmond Reservoir. It will then outline two to four optimum designs for streambank stabilization in this region in great detail, including the concepts behind each design and information from validation testing of the designs. Each design will be backed by an explanation of why the processes in that region optimize that method or combination of methods, including data from both site characterization and scale model testing. Each design will include guidelines for installation, maintenance, and cost of that method.

   1.1. **Knowledge of Regional Sites:** Characterization of bank and bank-river system parameters specific to the Neosho Headwaters Watershed is necessary to determine optimum stabilization designs for the region.

      1.1.1. **Priority Site Selection:** Priority site selection has been completed based on recommendation in the WRAPS document for sediment load reduction. The Kansas

Water Office assisted with recommendations specific to those sites within the Flint Hills National Wildlife Preserve.

1.1.2. Rapid Geomorphic Assessments (RGAs): The Channel Stability Index calculation completed through this method not only gives another perspective on bank priority or urgency of stabilization, but also allowed the team to better understand the processes at work in erosion of these particular banks, and the differences between banks in the same priority ranking in this region. These were completed following the first site visit in November 2014.

1.1.3. Flow Data: Obtained from the USGS stream gauge database.

1.1.3.1. Hydrologic Frequency Analysis: A characteristic 100-year peak flow (as well as several lower return period peak flows) has been determined for this reach of the Neosho using the Log Pearson Type III method of hydrologic frequency analysis as recommended by the USGS for rural streams and stream reaches. This will aid in scale modeling and give an idea of flow velocity and fluvial shear force the stabilized bank will need to resist.

1.1.4. Bank Material Characteristics: These include but are not necessarily limited to the soil type, bulk density, typical moisture content, erodibility coefficient, and geotechnical parameters. Some were able to be determined using bank soil samples retrieved during the November 2014 site visit. Unfortunately, jet erosion tests were not able to be performed at that time, postponing knowledge of erodibility coefficient to the second half of the project timeline.

1.2. Knowledge of Methods: Naturally, a thorough understanding of current methods of streambank stabilization is necessary to best be able to understand which methods are optimum for the region, which methods may be combined, etc.

1.2.1. Literature Review: An extensive literature review was conducted in September and October 2014. A summary of the same can be found in the Literature Review section of this report, in addition to a table detailing the uses, benefits, purposes, and complications of each method.

1.3. Recommendation Program

1.3.1. **Macro-Enabled Recommendation Spreadsheet:** Along with the guidance document itself, the client will be provided with a program in the form of a macro-enabled Microsoft Excel spreadsheet which will detail the benefits and complications of various optimum methods based on user inputs including but not limited to physical site characteristics. Overall, the spreadsheet will remain specific to the Neosho Headwaters Watershed.

1.4. Validation by Scale Model: The second half of the project timeline devotes a large amount of time and resources to validating selected optimum stabilization methods by accurate scale model testing and assessment.

1.4.1. **Scale Model Parameters:** Decisions will be made in the first part of the second project phase as to exact scale of the models, location of materials, and acquisition of appropriate "bank" materials.

1.4.2. **Scale Model Construction**

1.4.3. **Scale Model Testing:** An appropriate scale of the erosion and bank material loss calculations will be developed in order to judge validity of methods against the minimum load reduction required in order to meet the John Redmond Reservoir sediment TMDLs.

1.5. Documentation

1.5.1. **Statement of Work:** See the Statement of Work section of this report.

1.5.2. **Fall Semester Report:** A design proposal report must be completed and presented for client approval at the end of the first half of the project timeline. This is that document.

1.5.3. **Spring Semester Report:** A final design report detailing the team's complete and final decisions with regards to optimum designs and validation results will be presented to the client in May 2015.

1.5.4. **Final Guidance Document:** See the first item in this Work Breakdown Structure; this document will be completed and presented to the client in May 2015.

1.6. Communication: Results and progress will be communicated on various occasions.

1.6.1. **Fall Semester Presentation:** The design proposal (essentially, the contents of this report) will be presented to the client in an open presentation in December 2015.

1.6.2. **Spring Semester Presentation:** The final design will be presented to the client in an open, official presentation in May 2015.

1.6.3. **Spring Semester Demonstrations:** A tentative plan is for one or several of the scale models (reconstructed if necessary) to be moved to the BAE Laboratory for the BAE 4023 class design open demonstrations, to occur on the same day as the final design presentation.

Literature Review

This section details journal articles, research projects, patents and other documents needed to progress with the project. These include documents intended to guide testing, modeling and evaluation of the problem as well as methods to remediate the problem.

Methods of Streambank Stabilization

Before the major categories and specific methods of streambank stabilization are discussed, it must be mentioned that not all of these methods serve the same purpose. Some common methods of streambank stabilization focus only on protecting either the top or the bottom portion of the bank. Other methods focus on reducing or filtering runoff before it enters the stream, which is not the most direct approach to solving our objective. In any case, the descriptions of each method or category of methods which we have found relevant will include the scope or purpose of each method.

Streambank Re-grading

In many cases in which a stream has been undercut (the “toe” or bottom part of the stream has been eroded away) or incised (in which erosion has caused sloped banks to become vertical or near-vertical), movement of the bank material is often necessary. As seen in Figure 1, a sloped bank can then be re-created based on analysis of the stability of the native material at the site. Depending on how the work is done (usually with construction machinery), this process can be more or less intensive, but is generally considered low-cost. It is sometimes, though rarely, used as a method unto itself. In many cases, however, in order to protect the bank once re-graded, this method is used only as a “first step” (TVA, 2014).

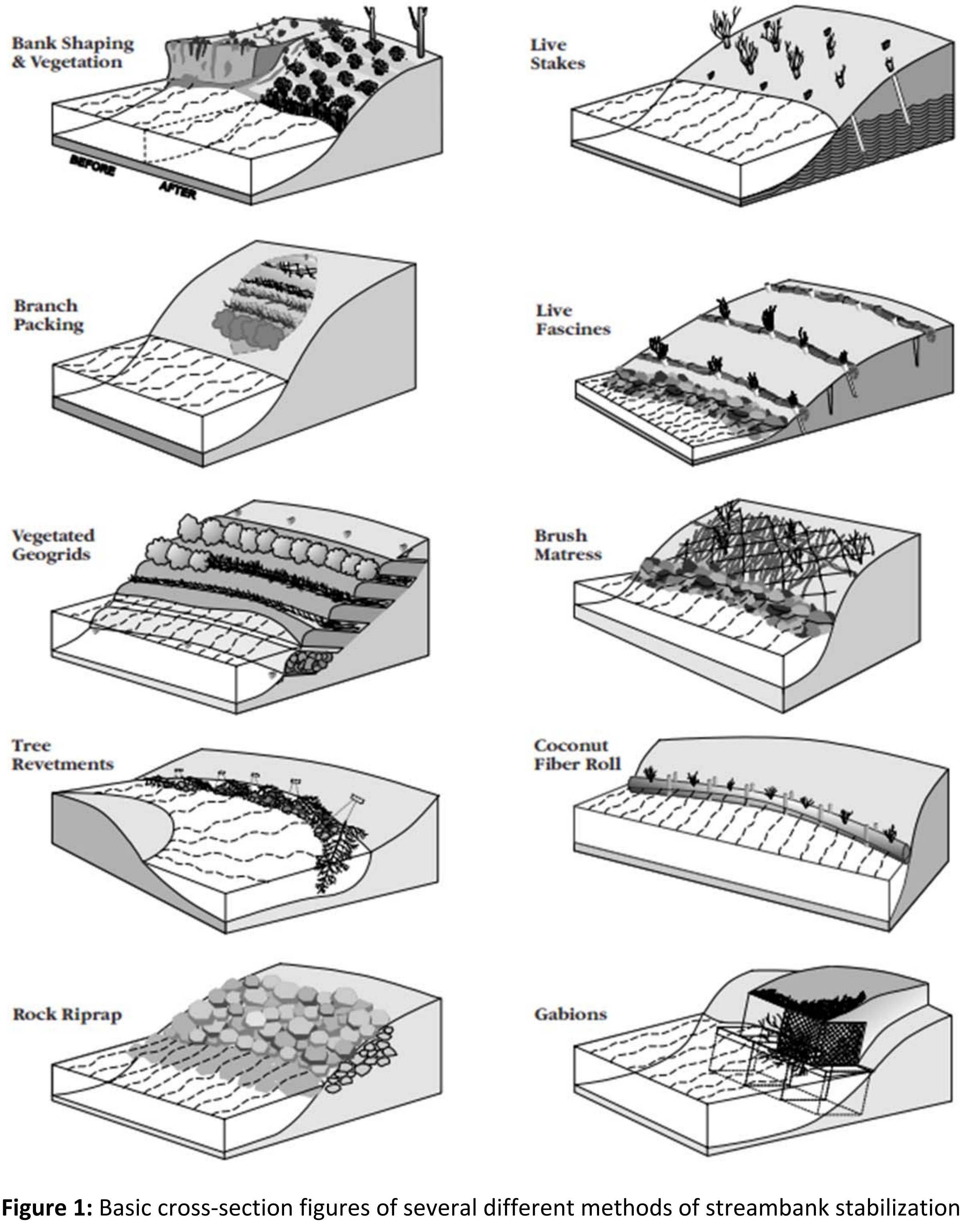


Figure 1: Basic cross-section figures of several different methods of streambank stabilization (TVA, 2014).

Natural Streambank Stabilization/Restoration

It is accepted among the stream conservation community that plant roots are one of the best ways to keep bank material (soil) in place. These methods are also highly desirable because of their friendliness to the stream ecosystem. They are almost always implemented with the hope that after a certain period of time, the bank will be healthy, stable, and accepting of native natural life.

Vegetation Alone

Fully grown or well-developed trees, shrubs, and other plants are planted directly onto re-graded banks. While this method is inexpensive and only moderately labor-intensive, it is risky if used alone, as flooding or high flow events can easily rip plants from the bank if they do not have well-established roots at that time (TVA, 2014).

Live Stakes/Whips/Spiling

A live stake is a living but dormant cutting of a woody plant which is placed (staked) into the streambank. The vegetation can then put down roots. Live stakes can be used alone or to hold other stabilization materials in place, as shown in Figure 2. Live whips are similar but much thinner and longer, and used more often for banks with normal high water content. Since stakes and whips often grow into trees and shrubs, they are used to protect the upper slope of a bank. They are inexpensive and not labor-intensive (Anstead and Boar, 2011).

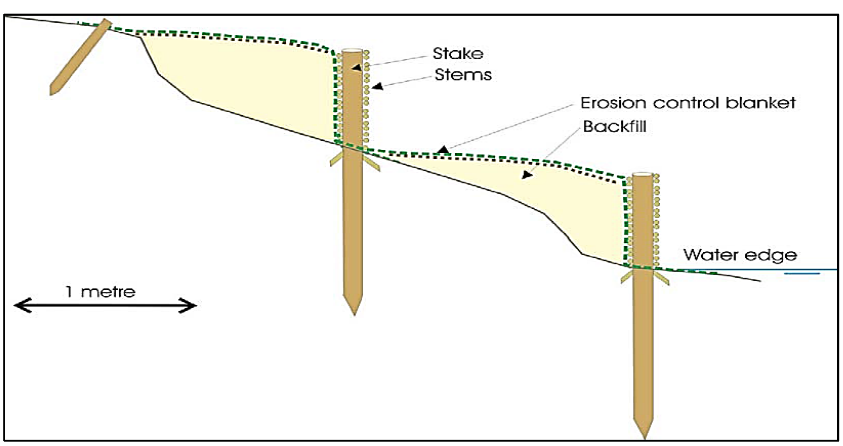


Figure 2: Live stakes (Anstead and Boar, 2010).

Joint Plantings

A joint planting system complements the use of live stakes by protecting the toe of the bank. Rock is laid down on the bank, and live stakes or similar woody material placed in the "joints" between the rocks, as can be seen in Figure 3. Eventually, once the vegetation becomes large and established enough, the rocks might be removed. Because of the use of rock and the long-term maintenance requirements, this method is moderately expensive and labor-intensive. The vegetated gabion method does essentially the same thing, but using gabions rather than riprap (Sotir and Fischenich, 2007).

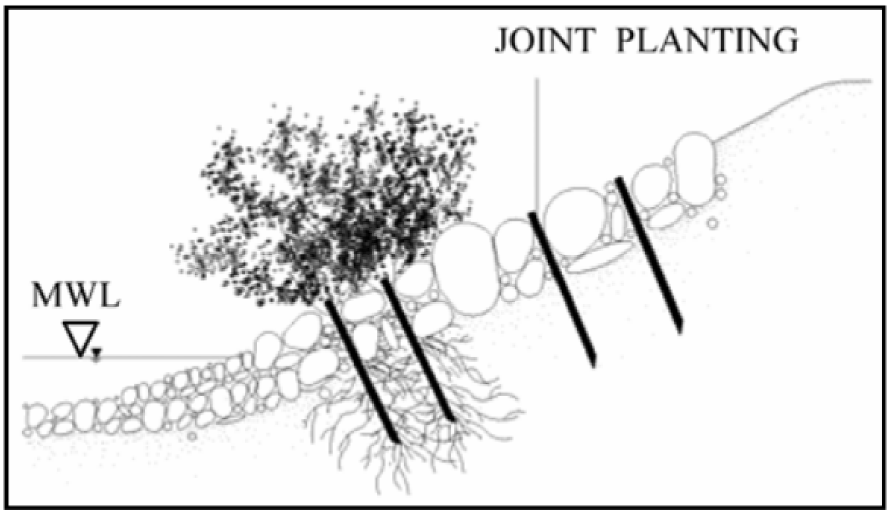


Figure 3: A joint planting installation (Sotir and Fischenich, 2007).

Brush Layering

Long branches of woody materially are placed thickly on a slope and covered with soil until only a bit of the branch is visible. The soil-covered brush then acts as a foundation for the next layer in a series of terraces. This method is also not terribly expensive, but much more complex and time-consuming to construct (Lake and Dickerson, 2005).

Live Fascines

A fascine is a bundle of live branches, which are similar to but smaller than live stakes. They are placed vertically in shallow trenches in the sloped bank, which are then filled in with bank material. As shown in Figure 4, they are secured with dead woody stakes to prevent them from being carried away in high flow events. They are inexpensive and fairly low in labor requirements, and protect the upper part of a bank. The branch packing method does much the same thing, but is used specifically to fill holes or gullies in banks, especially if re-grading may not be necessary (FISRWG, 1998).

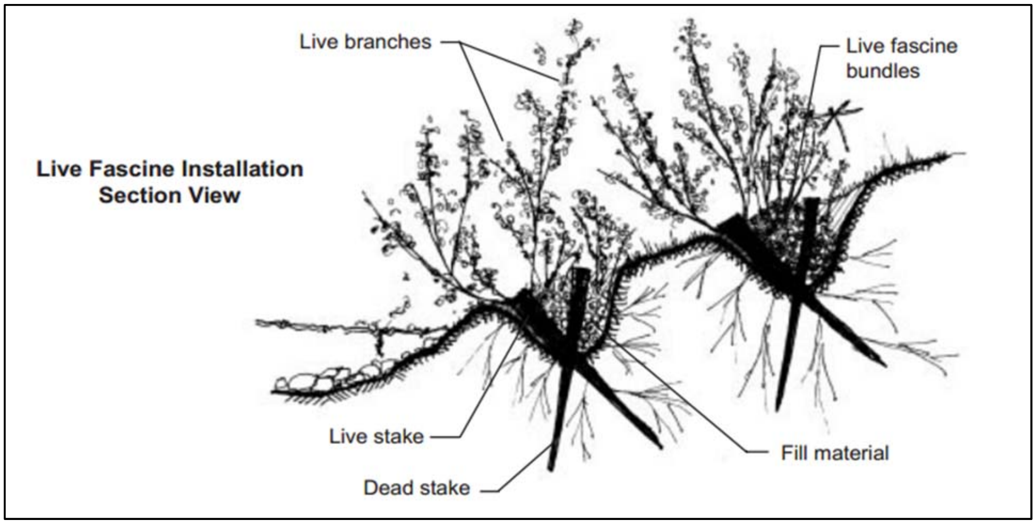


Figure 4: Live fascines (FISRWG, 1998).

Vegetated Geogrids

These work much the same as a joint planting or vegetated gabion, but instead of rocks, the stakes are inserted between clumps of compacted soil encased in geotextile material. An advantage of this method is that labor-intensive maintenance is not needed later to remove the rocks. This method may also be used in any portion of the back, near or away from the water line. However, this is a very expensive method (Geosyntec Consultants, 2006). See Figure 1 on page 9.

Brush Mattress

Woody material is layered horizontally along a streambank and held in place by live stakes (or metal stakes, and possibly wire). This mattress protects small seedling trees and brush, as well as seed plantings, from being washed away by storm runoff or high flows. It is understood that this is only viable for the upper bank and a very secure method such as riprap is often used to protect the toe and keep the mattress from being carried away. Figure 5 shows a brush mattress treatment applied in conjunction with a weighted rock toe. It is moderately expensive and complex option that works extremely well under a specific set of circumstances such as sunny locations with perennial stream flow and a moderate percentage of clay in the soil for stake anchoring (Allen, 2001).

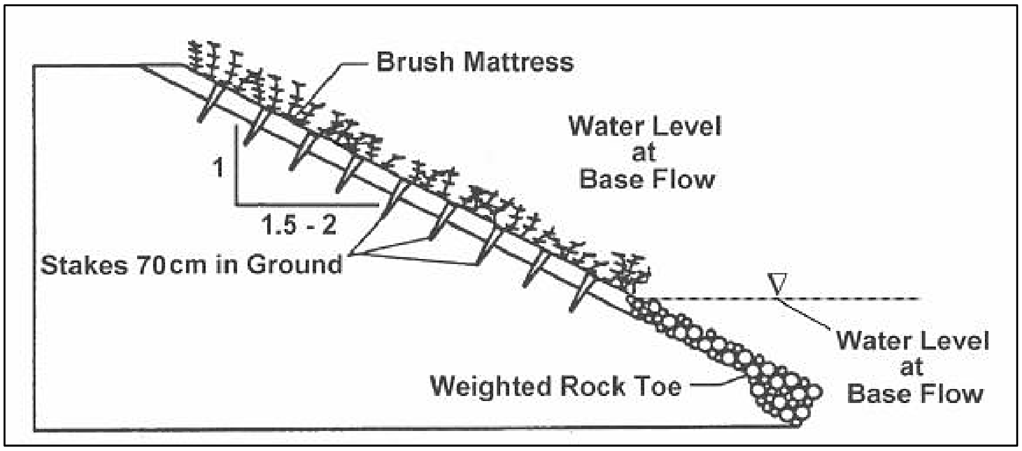


Figure 5: Profile view of brush mattress with rock toe (Allen and Fischenich, 2001).

Tree Revetments

Cut trees are anchored along the toe of a streambank, as shown in Figure 1 on page 9. This method is low cost but labor-intensive, and must often be combined with a separate technique to protect the upper bank. Rather than simply holding soil in place, these cut trees also work to absorb high flow energy, “taking the blows” that might erode the soil (Streams for the Future, 2014).

Fiber Rolls

These work much like tree revetments, except that rolls of coconut hulls (see Figure 6), other natural fibers such as straw, or synthetic fibers wrapped in a close netting or loose-weave cloth are placed at the bank toe to absorb flow energy. Though not exactly inexpensive, this method is less expensive than tree revetments and also less labor-intensive. Also like tree revetments, it is best when paired with another technique for the upper bank. However, it is only recommended for areas with constant flow (without common high flood events), as the roll is not as securely fastened to the bank (McClean, 2000).

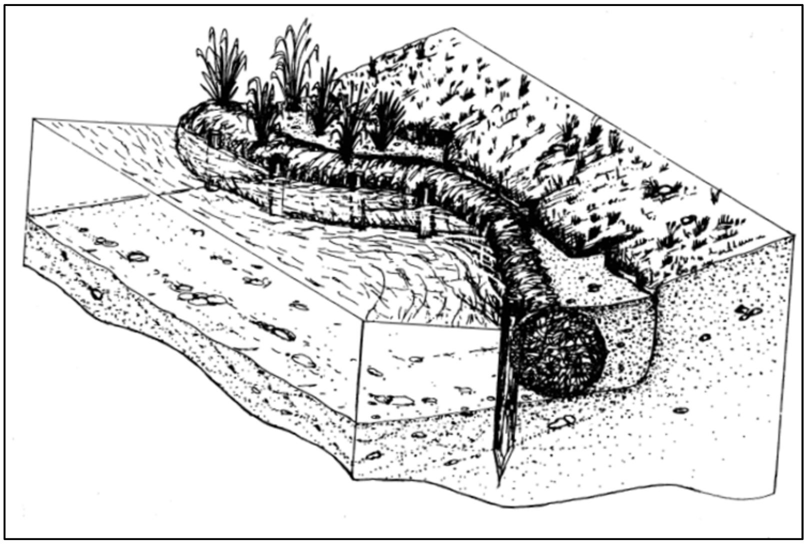


Figure 6: Placement of coconut fiber rolls along the toe of a bank (McClean, 2000).

Structural Streambank Stabilization

Riprap

Riprap protects the toe of the bank much like its biological counterparts, the tree revetment and fiber roll, by absorbing flow energies and deflecting them away from the bank material. Riprap consists of hard, medium sized (human fist to head-sized) stones placed into the toe of the bank. Placing riprap is moderately expensive and labor-intensive, yet it is often paired with a biological upper bank protection mechanism. See Figure 7.

Figure 7: Riprap along a coastal shoreline in Florida (Garland & Garland, 2014).

Gabions

Gabions are essentially riprap encased in wire baskets, which prevent the rocks from being carried away during floods. Though labor-intensive and very expensive, gabions also eliminate the need for bank re-grading because they can be placed vertically. See Figure 8.

Figure 8: Gabions along an English streambank (Gabion Erosion Control, 2014).

Concrete

Lining the stream walls with concrete prevents the water from ever reaching the soil, thus eliminating erosion risk from the stream itself. This is a very expensive and complex process, but one which eliminates the need for bank re-grading.

Rock Vanes

These methods disperse water energy by redirecting towards the center of the stream by means of large boulders placed in the stream itself. This is a method of high cost and moderate labor intensity. Specific types of rock vanes include j-hooks, cross vanes, and w-vanes (Brannaka, 2005).

Summary of Methods

These approaches toward achieving streambank stabilization represent a wide range of solutions which offers our team a broad spectrum of ideas to further analyze. Many of the presented methods are accompanied by drawbacks, but they provide our team with foundational information for developing a recommendation matrix spreadsheet. Table 1 qualitatively summarizes the aforementioned treatments.

Table 1: Basic outline of methods and qualities of each possible method.

Method	Protects		Combinations Possible	Complexity	Labor Intensity	Cost	Maintenance
	Upper Bank	Toe					
streambank re-grading	x	x	yes; necessary	low	moderate	low	low
vegetation	x	x	yes; necessary	variable	low	low	moderate
live stakes	x		yes	low	low	low	low
joint planting	x	x	yes	moderate	high	high	high
brush layering	x		limited	moderate	moderate	moderate	low
live fascines	x		yes	moderate	low	low	very low
vegetated geogrids	x		limited	high	high	high	very low
brush mattress	x	x	yes	moderate	moderate	moderate	moderate
tree revetments		x	yes	moderate	moderate	moderate	high
fiber rolls		x	yes	low	variable	variable	high
vegetated gabions	x	x	limited	moderate	high	high	high
rock vanes		x	yes	moderate	high	high	low
erosion control blanket	x		yes	low	moderate	variable	low

Analysis Resources

Other documents to help with our research and design include Kansas water regulations, previous analyses of the area watersheds and economic data related to land and water use in the area. Other resources include the Greenbank program (NCHRP, 2004), a generic design recommendation program which includes a database with a wealth of information about a multitude of stabilization and restoration methods for different purposes.

Government Documents

Several documents were found which are designed to help those wishing to implement stream restoration practices do so in the Neosho River Headwaters Watershed (or the state of Kansas as a whole). These documents outline guidelines and emphasize Kansas regulations. These include the most recent edition of the *Kansas Water Plan* released by the Kansas Water

Office in 2009, and the previously mentioned John Redmond Reservoir WRAPS document, released in 2010 by KCARE and the KSRE.

Risk-Benefit Analysis Guidelines

Expense, environmental benefit, and social benefit must be taken into account when selecting a method or combination of methods for streambank stabilization. A paper was found which presents models for conducting risk-benefit analyses on streambanks. On this sort of project, qualitative and quantitative (with the latter mostly focusing on cost) variables must be taken into account (Niezgoda and Johnson, 2012). Another paper suggests that a more technical analysis be used, taking into account geomorphological and hydrological equations and variables to calculate expected force and stress upon the bank and how that bank might be altered or protected to meet projected flow velocities (Frothingham, 2008).

Patents

A patent search for streambank stabilization and erosion control revealed several relevant examples.

- **Bank Mattress/Shore Protector (Neale, 1895):** This patent was referenced by several recent patents. A mattress constructed by weaving and quilting hay, straw, small trees, or brush with wire and secured to the bank with stakes and cables. See Figure 9.

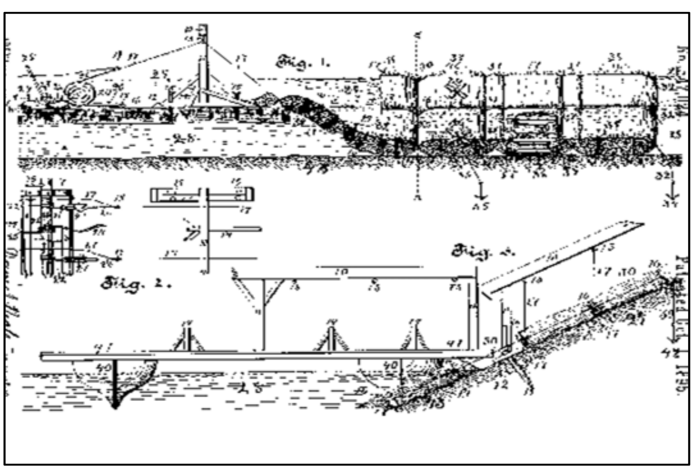


Figure 9: An early stream stabilization method (Neale, 1895).

- **Biofilter Bags (Grabhorn, 2000):** This method consists of a flexible mesh bag filled with wood and stump waste that prevents soil erosion by encouraging sediment deposition as water flows through the bag. Mostly used for temporary control during construction or other disturbances.
- **Erosion Control Block (Kelsey, 2013):** This method uses a flexible fibrous block that conforms to the contour of a streambank and is secured to the bank with stakes and tethers. This system slows water velocity and filters out sediment.
- **Excelsior (Johnson, 2005):** A net erosion free control blanket made from wood wool is placed atop the area of concern to protect it from erosive forces. It is environmentally friendly, as it provides the covered area with nourishing mulch as it decomposes. Vegetation grows in the place of this blanket which in turn decreases the amount of erosion in that area. A major drawback concerns the type of material used to bond the blanket together. Although the traditional threading material used is photodegradable, wildlife attempting to reside in the blanket gets trapped within it. Latex was initially suggested as a different threading material, but it becomes costly. The more recently proposed blanket incorporates a stitching strategy that uses wood wool as the threading material. See Figure 10.

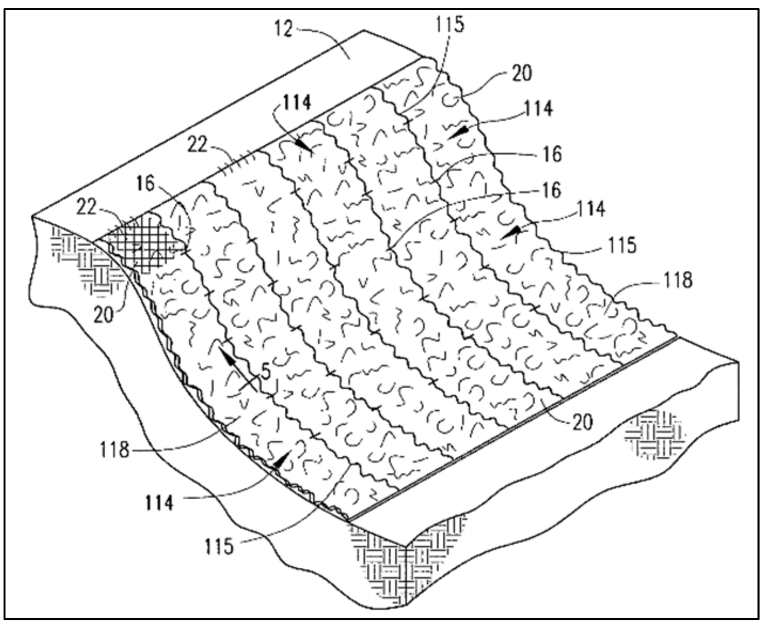


Figure 10: Excelsior net erosion free bank control blanket (Johnson et al, 2005).

- **Fascine/Shore protector (Keller, 1908):** This patent was referenced by several of the recent patents for shore line and streambank stabilization. A fascine constructed by placing several large wooden stakes into the bank or shoreline from the stream or lake bed to the top of the embankment. On the lower levels, beds of intertwined brush, saplings and small trees are secured to the stakes. The upper levels hold large, cylindrical bundles of brush, saplings and trees, which filter the water and encourages sediment deposition.
- **GreenLoxx, Filtrex FilterSoxx, Filtrex GreenMedia (Tyler, 2002 & 2014):** Growing medium, anchoring system, and tubular mesh enclosure for use as an erosion control system by providing a barrier that encourages riparian vegetation growth while ensuring firm anchoring to the bank. See Figure 11.

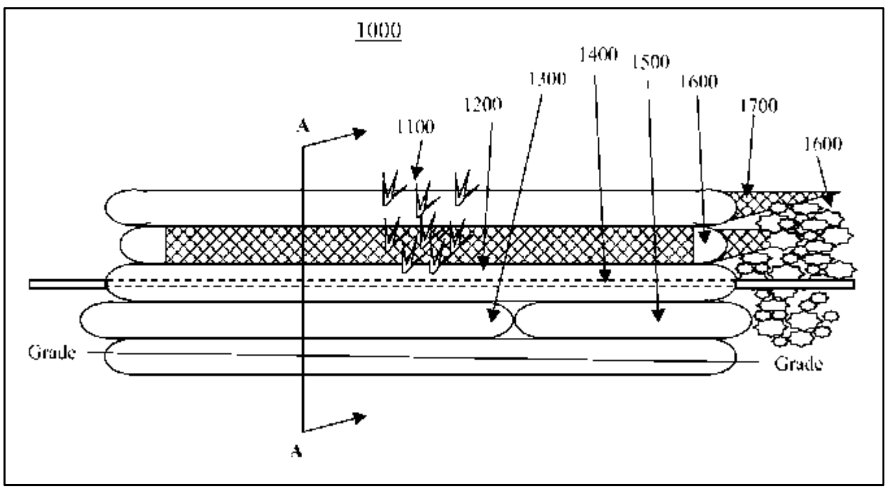


Figure 11: FilterSoxx (Tyler, 2014).

- **Revetment (Bestmann, 1997):** A plastic, net-like structure encasing soil and substrate material and plant seeds. The individual chambers are bound together into a long, cylindrical single unit and anchored to banks with steel cable and anchor plates. This system allows for erosion control for steeper streambanks often found near shipping channels or from extreme flow events.
- **Silt fence (Christopher, 2013)/Silt Fencing Unwinder (Murphy, 2012):** Made from a geotextile fabric and supported by stakes against the walls of lakes, rivers, or streams, the purpose of these temporary fences is to keep silt from entering the water during

construction or temporary disturbance. The unwinder cuts manual labor costs which is one of the biggest drawbacks to this method. In addition, the unwinder apparatus can be constructed from plastic, composite, sheet metal, or any smooth and durable material.

- **Vegetation Blanket (Wang, 2011):** A vegetation blanket is made with yarn and consisting of interwoven mesh structures that are used to stabilize streambanks by securing soil and vegetation to ensure plant establishment.

Technical Analysis

The following section describes methods of data collection, testing and modeling in order to characterize the regional bank parameters

Data Collection and Testing

First, any information that could be gathered using existing databases and purely analytical methods was researched. Next, the team conducted a site visit to the Flint Hills National Wildlife Refuge upstream of John Redmond Reservoir. Figure 12 shows a view from Site 34 in Priority Group 3.

Figure 12: Site 34 in Priority Group 2 of the Neosho Headwaters Watershed, *personal photo taken during site visit on November 15, 2014.*

Seven of the priority sites in the Neosho Headwaters Watershed were visited, and some preliminary testing and visual analysis was accomplished in order to better understand erosion processes and bank properties of the reach.

Hydrologic Frequency Analysis

Yearly peak flow data for gages near the priority sites was evaluated from the United States Geological Survey (USGS). The USGS stream gage near Americus provided a reliably long record, more than ten years, while still being upstream of the site and fairly close. Using the Log Pearson Type III (LP3) method of hydrologic frequency analysis (USGS and KDOT, 2000), characteristic peak flows were calculated for several return periods as a rough estimate of watershed behavior (Haan et al, 1994). As can be seen in Table 2, any methods designed will have to stand up to very high flows during flood events and include adequate protection and stability for any emerging bank vegetation during its establishment period.

Table 2: Return period and predicted peak flows at the Americus Neosho River stream gage

Return Period (yrs)	100	50	25	10	5	2	1
Peak Flow (cfs)	21,600	19,500	17,300	14,000	11,200	6,900	1,100

Rapid Geomorphic Assessments

This measurement combines geometric parameters and visually-assessed bank protection quality, taken on site, in a spreadsheet to compute a channel stability index (CSI) which serves as another measure of stabilization urgency. A higher score represents a channel or streambank which is much less stable. At almost all seven sites, only one bank (the priority bank of interest) shows any signs of erosion. As seen in Figure 13, the opposite bank has a much gentler slope and features large trees and established brush of various native species.

Figure 13: Site 29 in Priority Group 2 in the Neosho Headwaters Watershed, *personal photo taken during site visit on November 15, 2014.*

Thus, the scores seen in Table 3 are lower than might be expected in a channel where both banks are in equally poor condition (Heeren et al, 2012). Note that the average score from Priority Group 2 banks is higher than those from Priority Group 3. These overall scores will be useful in determining which banks to design solutions for first. However, the details of the assessments will also be extremely helpful in determining the major characteristics and erosion processes of the region.

Table 3: Channel Stability Index scores of priority sites on the Neosho River

	Priority Group 2					Priority Group 3	
Site #	26	27	28	29	30	33	34
CSI	17.5	22.5	21.5	16	22.5	13	19

Soil Characteristics

Soil cores from each site are used to calculate bulk density and soil moisture content. These give further information about the current condition of the bank by revealing the packing density and wetness of the soil, respectively, with a very loose, dry soil considered to be most susceptible for erosion. Unfortunately, the soil cores taken on the November site visit gave undesirable results because at that time, the banks had already frozen. Due to hydrogen bonding in water, water expands when frozen, making the pore volume of the soil appear to be greater than it would be in the spring months, when the river is historically at greatest danger for high flow events.

Separate soil samples were taken to determine geotechnical parameters using direct shear tests, which will be completed during the first weeks of the spring semester. These tests reveal information not about the condition of the bank, but about the basic properties of the bank material particles. Upon results analysis, direct shear tests yield the angle of internal friction (f) of the soil, from which the soil shear strength (s) can be calculated using the equation:

$$s = s * \tan f$$

These properties are necessary to know because they describe how much shear force the bank material will be able to resist. As a primary worry in this reach is fluvial erosion during high flow events beyond ordinary levels (i.e. floods), this becomes crucial in determining the best design solutions. In addition, these parameters are important when designing new bank slopes (Reddy, 2002).

Jet Testing

Jet erosion tests (JETs) are conducted to estimate the critical shear stress and erodibility coefficient of soils with cohesive strength (Daly et al., 2014). JETs are conducted with the jet apparatus itself as seen in Figure 14. The hoses shown in Figure 14 serve the purpose of cycling the water. One transports water back into the reservoir from the submergence tank while another connects a pump—powered by a 4-cycle gasoline engine—to a constant head tank set at some predetermined elevation above the jet apparatus. 2 feet of head is recommended as a starting point, but this can be adjusted based on the soil response to the JET process.

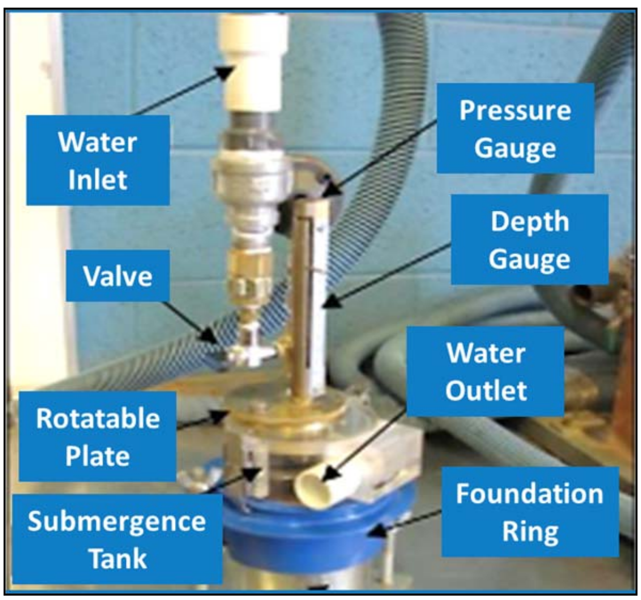


Figure 14: JET Erosion Testing apparatus (Daly et al, 2014)

A circular jet stream of water is then projected perpendicularly into the bank and the depth gauge measures the scour hole depth created by the jet stream. Thus, by measuring the scour hole depth over time, the erodibility coefficient and the critical shear stress can later be estimated from data. As the frozen quality of the bank soil prevented JETs from being taken during the November site visit, there are two main options moving forward. Another site visit could be taken in the spring semester, during the second half of the project. Alternatively, large quantities of soil could be brought to Stillwater in order to conduct a controlled approximation of the tests in the departmental lab facilities.

Modeling

Bank Stability and Toe Erosion Model (BSTEM)

In order to analyze the erodibility of the soil contained within the priority sites, data from the collected soil samples will be put through the Bank Stability and Toe Erosion Model (BSTEM), which is an Excel-based program. The bank stability portion of BSTEM calculates a variable called the bank factor of safety—a ratio of the resistive forces of a bank to the driving forces against it—which is compared to two ranges. If the value for the bank factor of safety exists between zero and one, the bank is classified as unstable, or highly erodible. Conversely, if the value is greater than one, the bank is classified as stable, or highly resistant. Specific bank factor of safety values are calculated for horizontal, vertical, and cantilever shear failures in stability. For the horizontal method, the bank can be separated into up to five user-definable soil layers, as seen in Figure 15, with geotechnical properties specific to each layer. BSTEM then calculates a bank factor of safety using an equation that incorporates pore-water pressure, the weight of each layer, and the geometry of the bank (Langendoen, 2013).

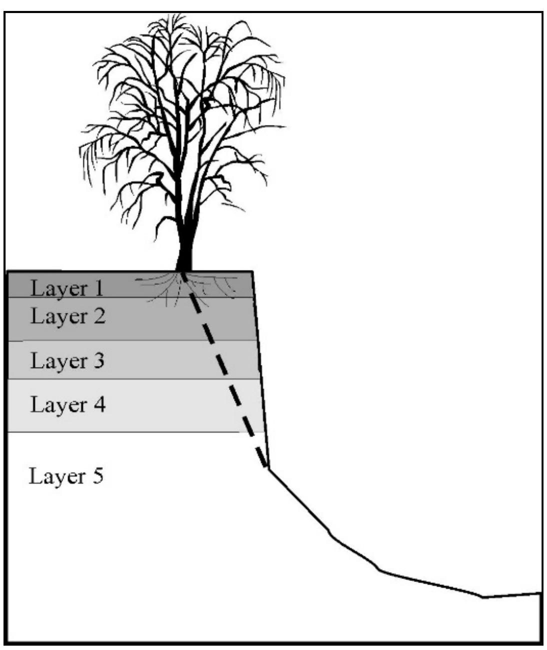


Figure 15: Example of soil layers for horizontal method (Langendoen, 2013).

The vertical failure analysis uses a slicing method which is visually demonstrated in Figure 16. The vertical forces—gravity and the vertical portion of the normal force—acting on each of the sub-slices are summed to determine the normal force acting on each composite slice. The horizontal forces acting on each composite slice are summed to calculate the inter-slice normal force. Inter-slice shear force is accounted for by a method programmed into BSTEM. The bank factor of safety concerning vertical failure is calculated by balancing the horizontal and vertical forces of each sub-slice and the horizontal forces for the entire bank (Langendoen, 2013).

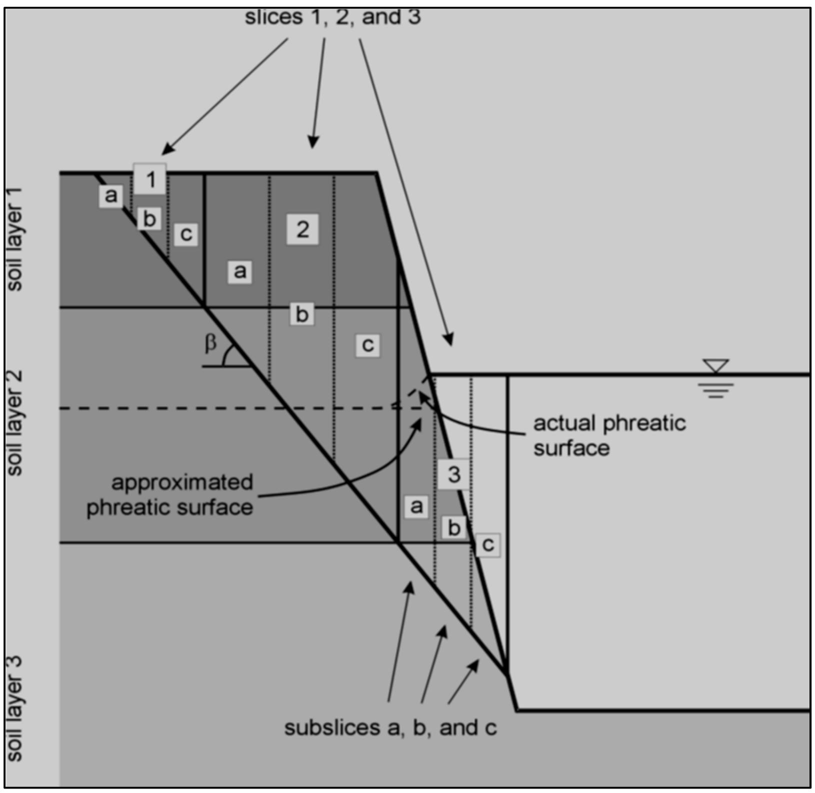


Figure 16: Example of the vertical failure analysis (Langendoen, 2013).

The cantilever shear failure algorithm calculates the bank factor of safety by dividing the shear strength of the soil to the weight of the cantilever. A variable is included in calculating the factor of safety for this method that correctly represents the effect of the water on the weight of the soil (Langendoen, 2013).

As for the toe erosion portion of BSTEM, the average applied boundary shear stress, maximum lateral retreat and total eroded area are calculated as our outputs as seen in Figure

17. Due to the fact that the typical equation for calculating boundary shear stress does not account for curvature, it can be accounted for by checking the box as seen below. In addition—similar to the bank stability portion of BSTEM—based on the inputs, the basal elevation changes from layer to layer combined with the eroded profile in comparison to the initial profile are graphically represented (Langendoen, 2013). The critical shear stress and erodibility coefficient are determined by using the JETs as discussed in the jet testing section.

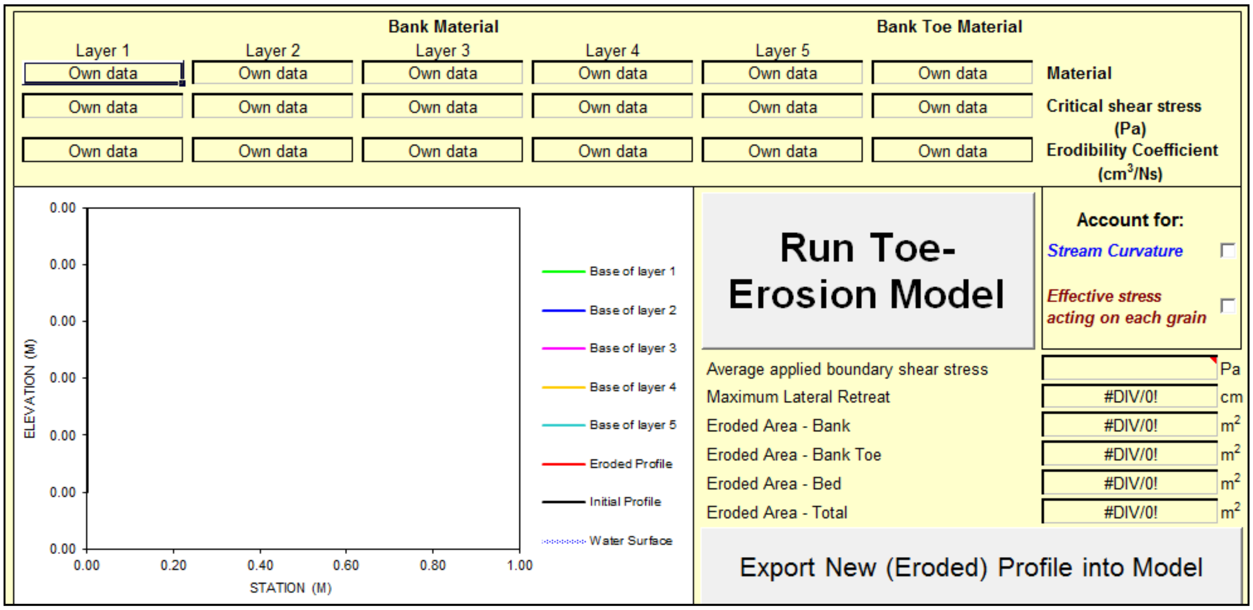


Figure 17: Toe erosion spreadsheet (Langendoen, 2013).

The data from the site visit in the spring will be used to complete this modeling.

Design Concepts

This section includes the design requirements directed by the US Army Corps of Engineers, the proposed designs, and the potential impacts.

Customer Requirements

The design must reduce silt loads in the Neosho River and consequently in the John Redmond Reservoir. The USACE has confirmed seven priority sites set by the Kansas Water Office (KWO) for evaluation and treatment. All sites are located in the Flint National Wildlife Preserve near Hartford, Kansas. Final deliverables should include recommended treatments for the priority sites as well as a guidance document detailing a cost/benefit analysis and instructions for installation and maintenance.

Engineering Specifications

The goal is to reduce the sedimentation rate in the Neosho River by 0.75 tons/foot of bank length/year. A scaled version of this specification will be used to judge this success of the designs of scale models.

Proposed Design

The final version of the Neosho Headwaters Streambank Stabilization Guideline will detail the ranges of typical streambank characteristics found in the watershed. It will detail two to four stabilization methods or combinations of methods, including uses, purposes, benefits, costs, complications, optimum situations, installation guidelines, etc., along with estimations of how much sediment load reduction will be effected by each method when implemented on real streambanks. This will be accompanied by a program consisting of a macro-enabled Excel spreadsheet which will accept user inputs of bank and stream characteristics and output a recommendation matrix which will take the form of costs and benefits specific to that bank for various methods.

Environmental, Societal or Global Impacts

The primary positive impact of this solution is to prolong the life of John Redmond Reservoir by reducing sediment loads in the Neosho River and thus helping the lake to retain its volume. This is important to society because the lake is a drinking water reservoir that is used, among other uses, for domestic public (drinking) water. Streambank stabilization also has the side environmental impact of sloped banks and vegetation providing better wildlife habitat, which is particularly important on streambanks in a wildlife preserve. This guidance document will use the common characteristics of the watershed, meaning it can be used outside of our priority site area.

Project Schedule and Budget

The following details proposed plans for the spring semester.

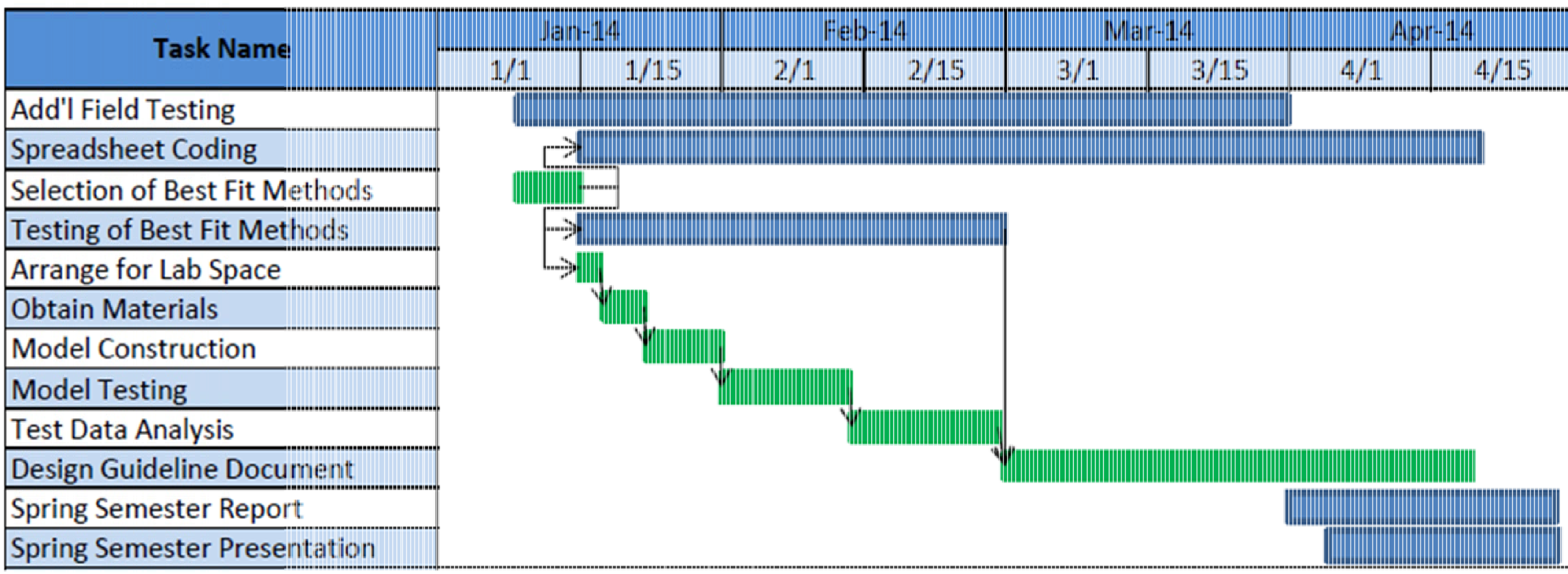
Budget

The proposed budget for the spring semester site visit will include transportation, lodging for the duration of the visit, and gasoline for the pump. The estimated cost of the transportation and lodging is $200, and that for the gasoline for the pump is $15. Additional expenses include supplies needed for the scale model which are estimated to be $300. Thus, the total estimated budget for this project is $515 for the spring semester.

Gantt Chart

The Gantt chart for the spring semester is on the following page in Table 4. The table includes tasks and a schedule to help guide the team's progress to the final presentation. A site visit is tentatively scheduled for March 2014 to collect more soil samples, conduct jet erosion testing and take more pictures of the vegetated banks. Scale model testing will be scheduled according to the availability of the USDA-NRCS Hydrologic Engineering Research Unit lab and facilities.

Table 4: Gantt chart for spring semester



Report Summary

Using field tests and regional site assessments, a recommendation matrix and comprehensive design manual will be created and delivered at the end of the spring semester in May of 2015. This will enable the USACE to act to solve the issue of sediment load in the Neosho River thus prolonging the life of John Redmond Reservoir.

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JOHN REDMOND RESERVOIR
STREAMBANK STABILIZATION

Hybrid Stream Solutions

Leslie Ogar, Emelia Brooks, and Lizzie Hickman

Prepared for the USACE – Tulsa Office

5 December 2014

OUTLINE

- Introduction
- Technical Analysis
- Stabilization Methods
- Design Proposal
- Spring Schedule
- Summary

Photo taken at Site 33 on 15 November 2014

JOHN REDMOND RESERVOIR

Map of John Redmond Reservoir (Google Maps, 2014)

- Finished in 1964
- Original capacity – 82,000 ac-ft
- 2010 capacity – 46,000 ac-ft
- Storage reduction – 42%
- Sedimentation rate – 738 ac-ft/yr
- First inland lake dredged by the USACE

NEOSHO HEADWATERS WATERSHED

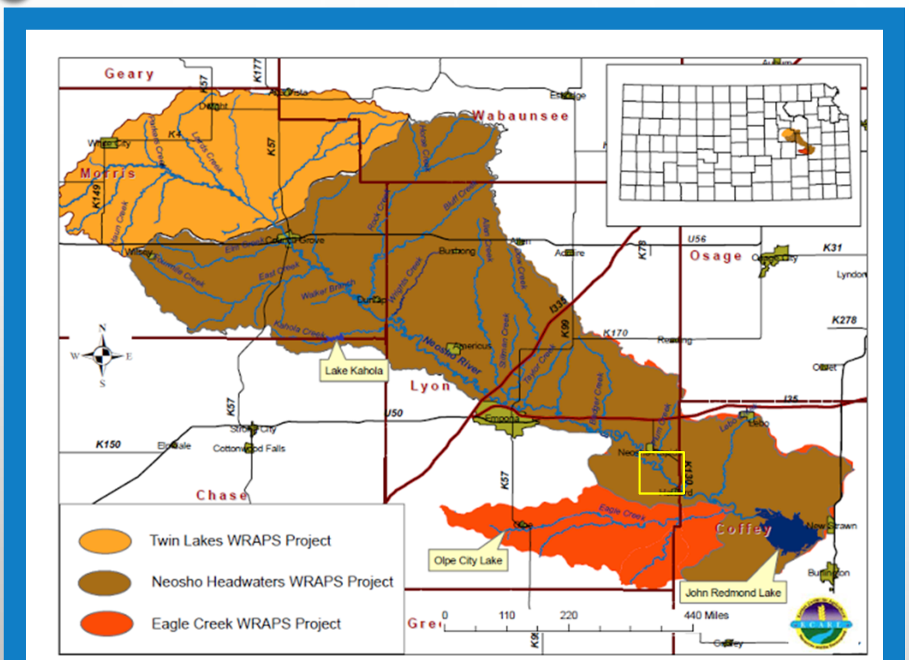
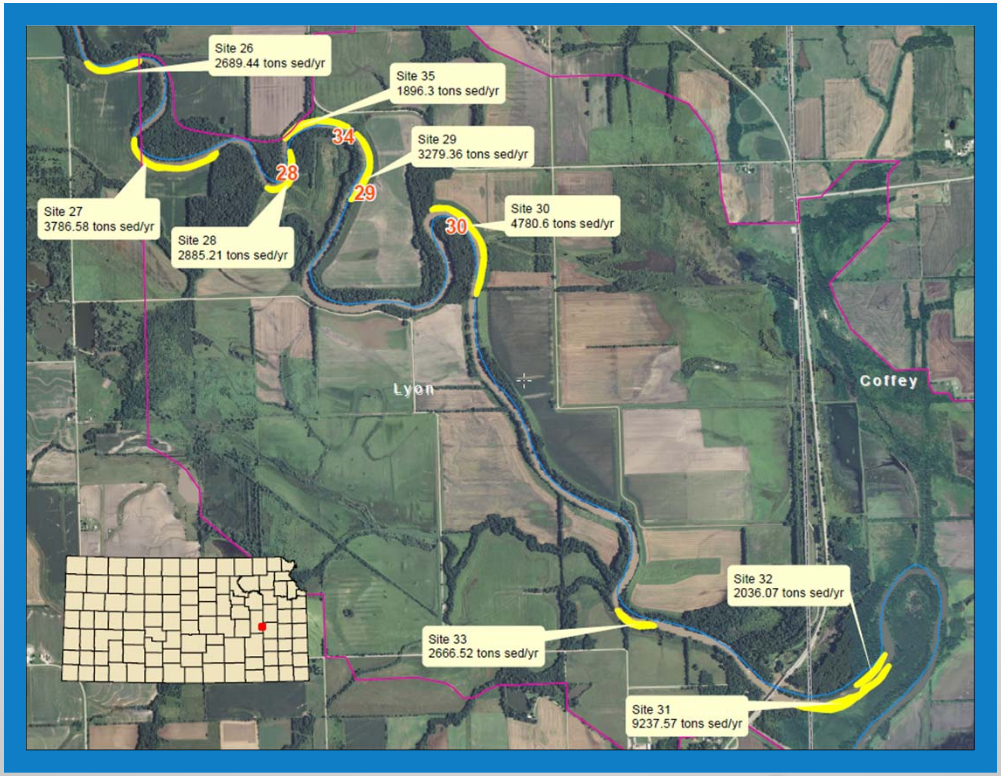


Figure 1. Map of Neosho Headwaters Watershed.

Map of Neosho Headwaters Watershed (KCARE and KSRE, 2010)

- Sediment TMDL—59,100 tons/yr set by KDHE
  - 29,760 tons/yr over capacity, in 2010
- Requires 0.75 tons/ft of bank/yr from each priority site
- Feasibility: will exceed required reduction

PRIORITY SITES



Map of priority sites from the Kansas Water Office (KWO, 2014)

INITIAL OBSERVATIONS

Photo taken at Site 30 on 15 November 2014

- November site visit
- Evidence of erosion
  - Fluvial erosion
    - Peak flow events
  - Undercutting
  - Mass wasting
  - Evidence of seepage
- Vegetation
  - <15% cover in bank
  - Trees and thick grasses on top

PROBLEM STATEMENT

Create watershed-specific guidelines for innovative, cost-effective designs to stabilize streambanks on federal land along the Neosho River to most effectively reduce sedimentation and to prolong the life of John Redmond Reservoir.

SPECIFICATIONS AND REQUIREMENTS

- Federal land
- Sedimentation reduction
  - 0.75 tons/foot of bank length/year
- Final deliverables
  - Recommendations
  - Cost/benefit matrix
  - Installation/maintenance guidelines

Photo taken at Site 29 on 15 November 2014

TECHNICAL ANALYSIS

- Hydrologic Frequency Analysis
- Rapid Geomorphic Assessments (RGAs)
- Bank Stability and Toe Erosion Model (BSTEM)
  - Toe Erosion
    - Jet Erosion Tests (JETs)
  - Bank Stability
    - Geotechnical Parameters

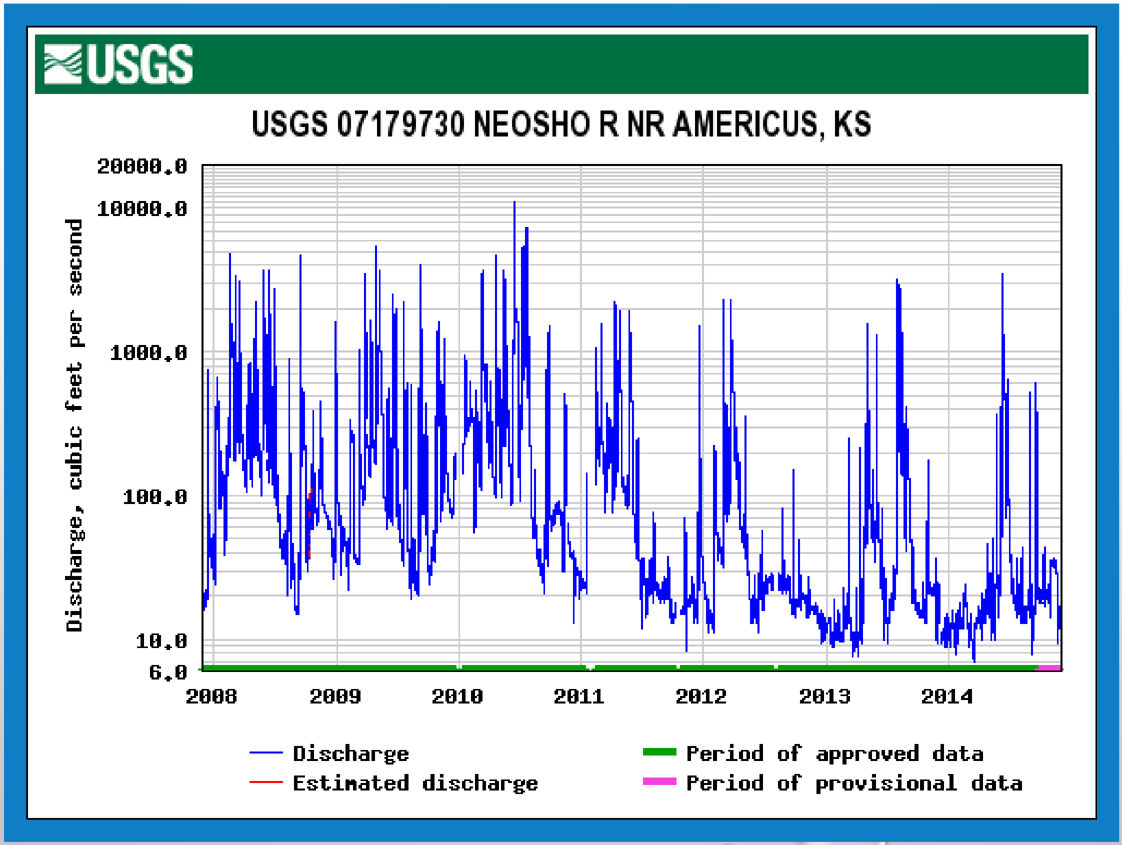
HYDROLOGIC FREQUENCY ANALYSIS

Table 1: Return period and predicted peak flows at the Americus Neosho River stream gage

Return Period (yrs)	**100**	**50**	**25**	**10**	**5**	**2**	**1**
Peak Flow (cfs)	**21,600**	**19,500**	**17,300**	**14,000**	**11,200**	**6,900**	**1,100**

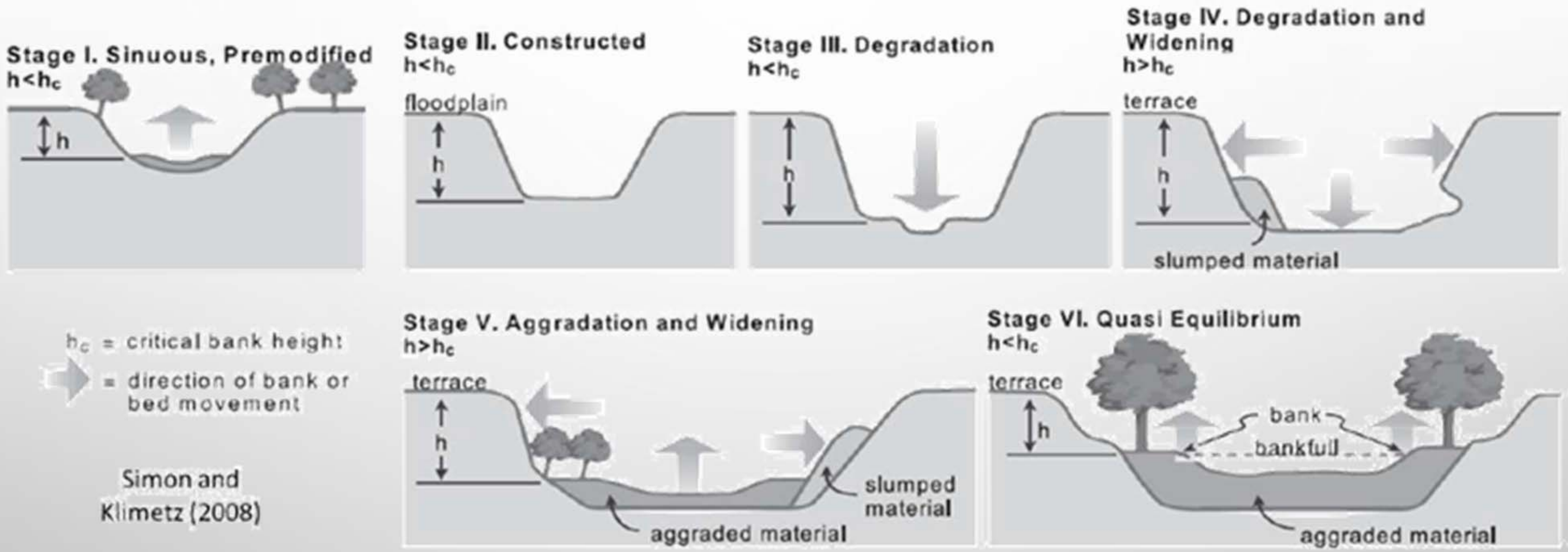
Calculated by freshmen from peak flow records retrieved from the USGS water database.

HYDROGRAPH



Graph produced by the USGS website from Americus, KS gage data.

STAGE OF CHANNEL EVOLUTION



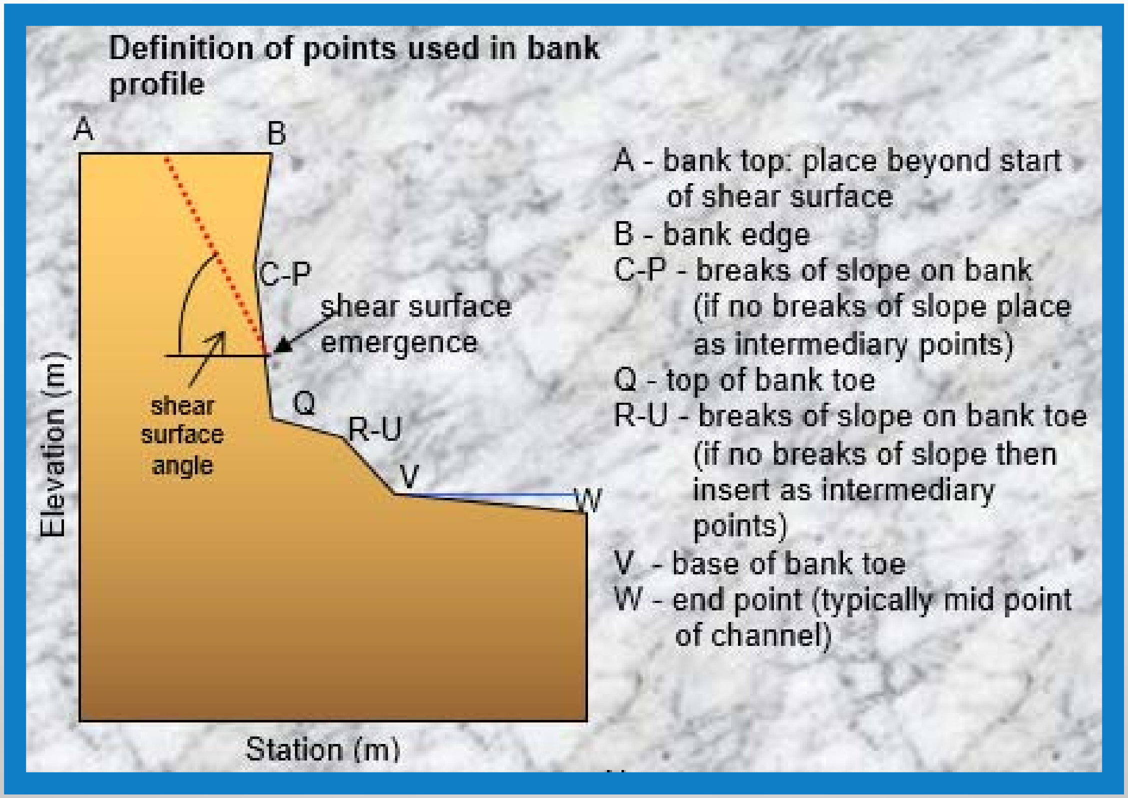
RAPID GEOMORPHIC ASSESSMENTS

Table 2: Channel Stability Index for priority sites on the Neosho River

	Priority Group 2					Priority Group 3	
Site #	26	27	28	29	30	33	34
CSI	17.5	22.5	21.5	16	22.5	13	19
Stage	3	4	4	3	4	5	4

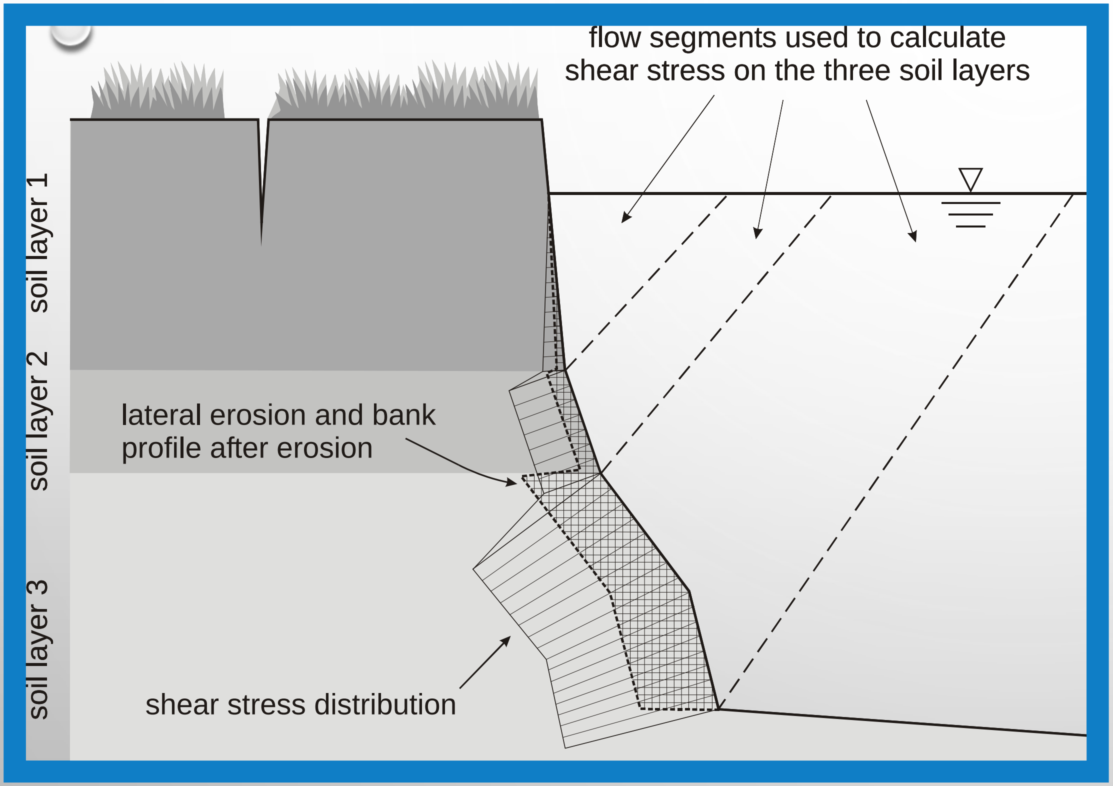
- Bank Geometry
- Vegetative condition
- Channel Stability Index (CSI)

BSTEM: BANK PROFILE SIMULATION



Bank Profile and Parameters (Langendoen, 2013)

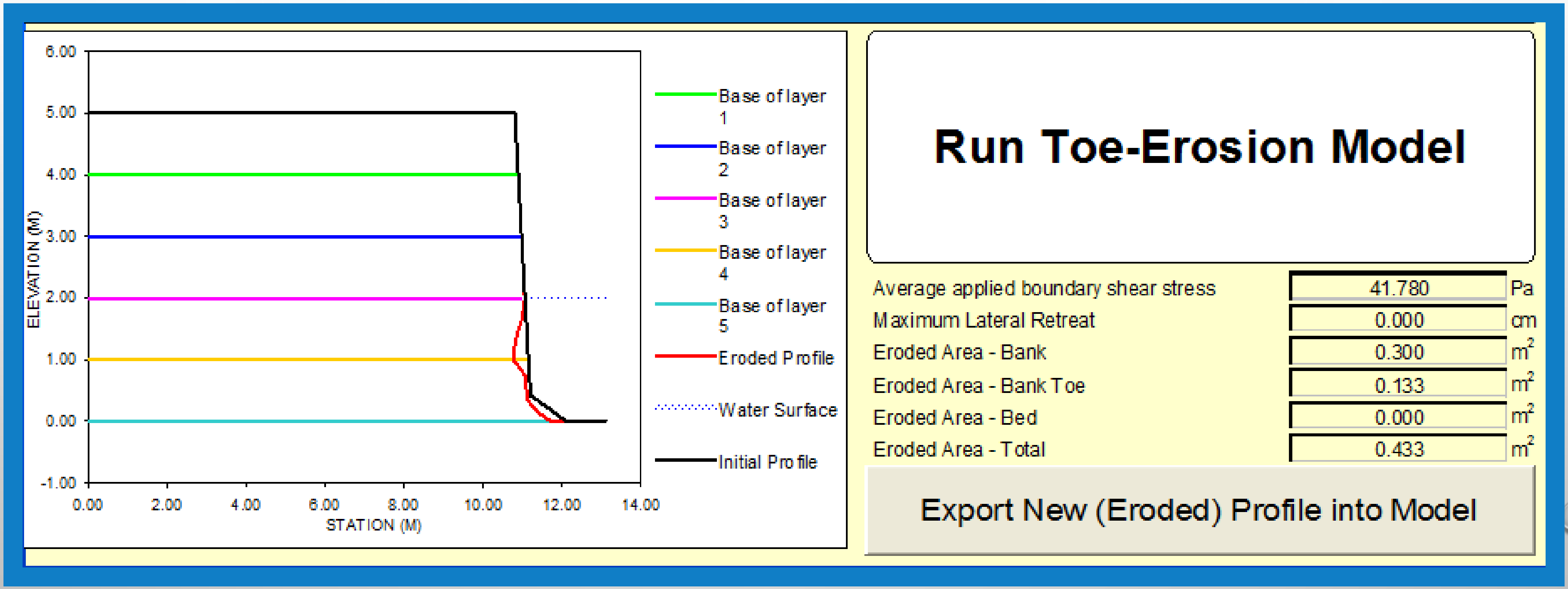
BSTEM: TOE EROSION MODEL



Segmentation for Shear Stress Calculation (Langendoen, 2013)

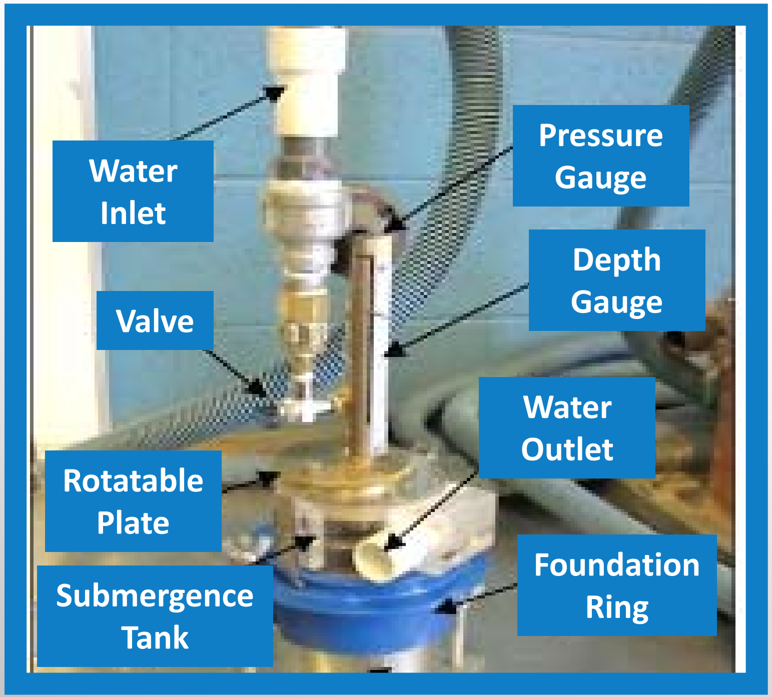
- Average boundary shear stress
  - Correction factor for curvature

BSTEM: TOE EROSION MODEL OUTPUT



Toe Erosion Model Output (Blankenhead et al., 2010)

JET EROSION TESTS (JET)

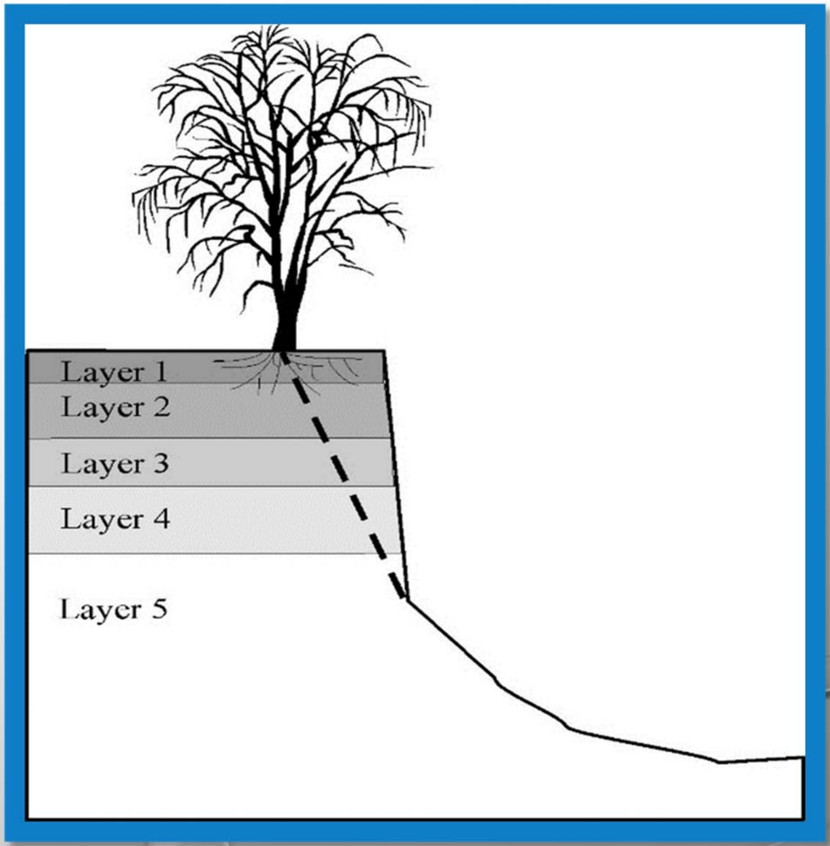


JET Apparatus (Daly et al, 2014)

- Critical shear stress
- Erodibility coefficient
- Scour depth
- Spring site visit

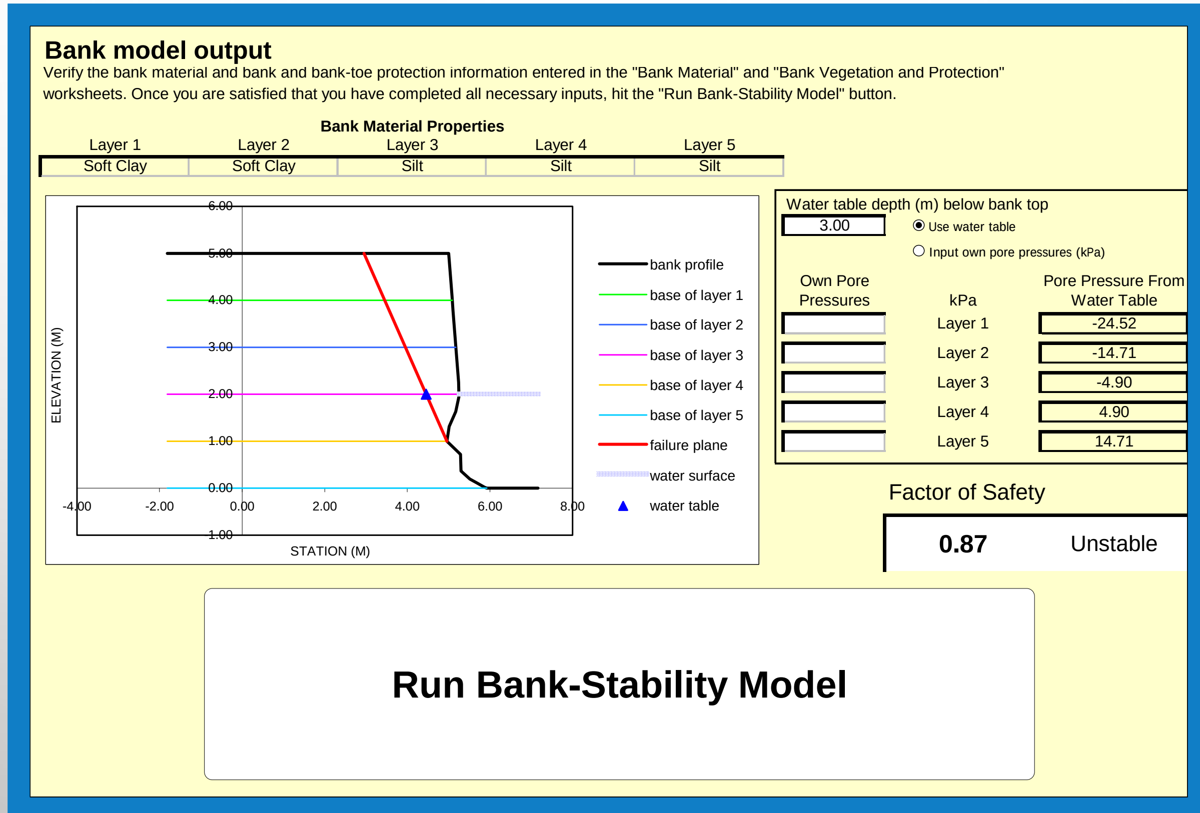
BANK STABILITY AND TOE EROSION MODEL (BSTEM)

- Bank stability portion of model
  - Bank Factor of Safety (F_S)
    - Resisting : Driving
    - 0 < FS < 1.0
    - 1.0 < FS < 1.3,
    - FS > 1.3
  - Up to 5 layers
  - Default values available



Horizontal Layers Example (Langendoen, 2013)

BSTEM: BANK MODEL OUTPUT



Bank Model Output (Bankhead et al., 2013)

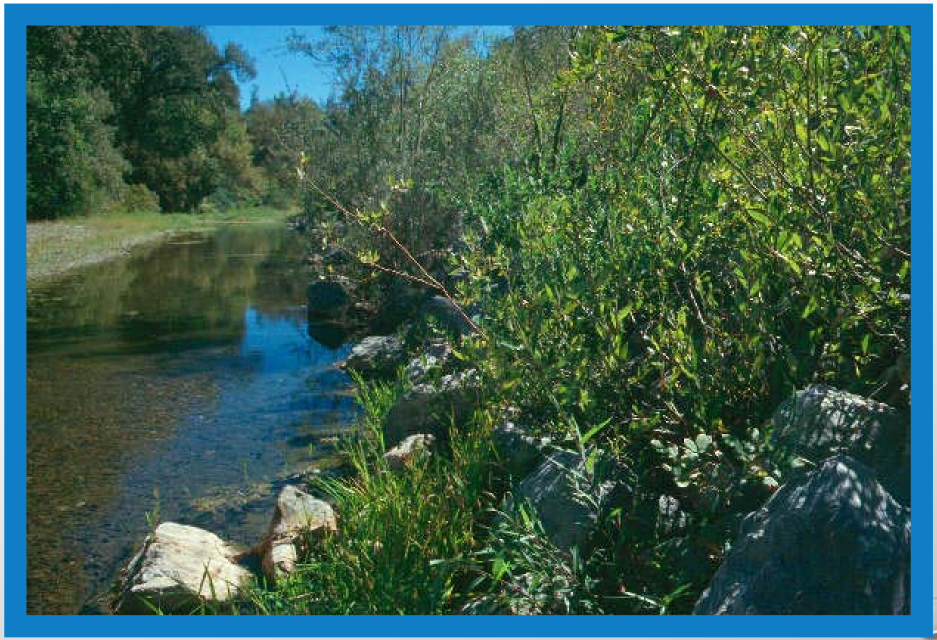
GEOTECHNICAL PARAMETERS

- Soil sampling
  - Bulk density
  - Soil moisture content
- Direct Shear Tests
  - Soil shear strength
  - Effective cohesion
  - Internal angle of friction

Photo taken during core sample analysis November 2014

METHODS OF STREAMBANK RESTORATION

- Serve different purposes
  - Upper bank vs toe protection
- Biostabilization
  - Soil anchoring
  - Ecosystem health
- Structural methods
  - Expensive and temporary



Vegetated Riprap: (TRB, 2004)

STREAMBANK RE-GRADING

Streambank Re-grading (Washington, 2003)

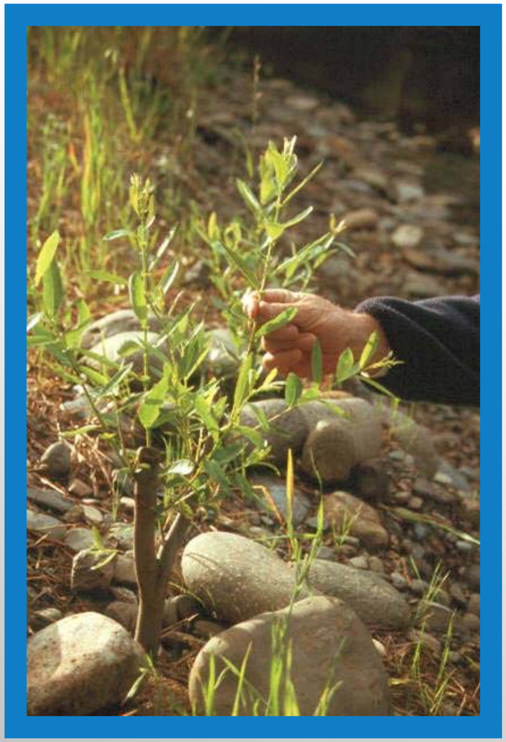
- Recreation of stable slope
- “First step” method
- Requires protection
- Based on properties of native bank material
- Slope requirements

VEGETATION

- Roots anchor bank material
- Requires 3:1 (H:V) bank slope
- Requires protection
- Establishment time
- Plant species data exists
  - Shear stress, velocity

Established Vegetation (TRB, 2004)

LIVE STAKING/JOINT PLANTING

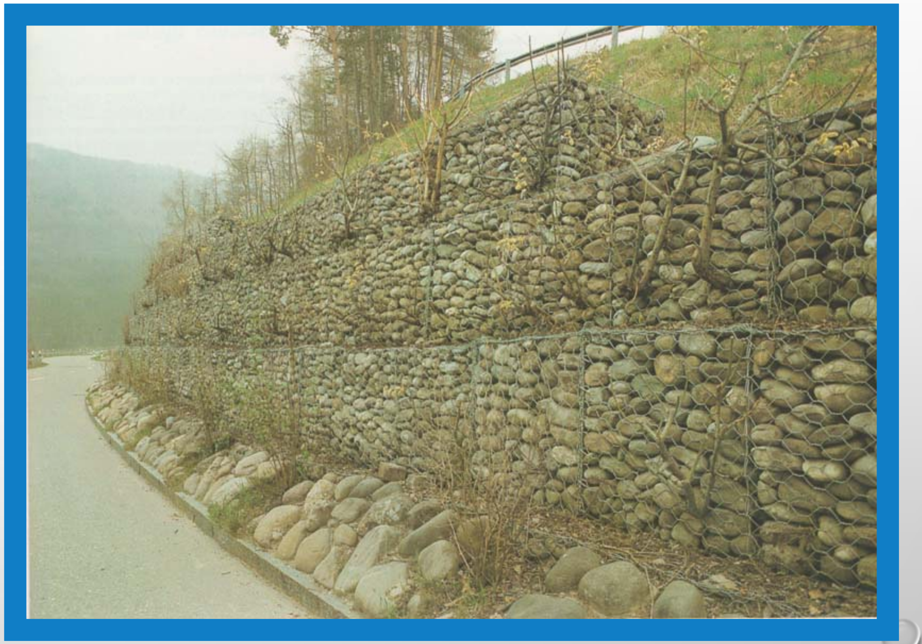


Growth of Live Stakes (TRB, 2004)

- Dormant cutting of woody plant material "staked" into bank
  - Good for high flow
- Joint planting adds riprap protection
- Removal after establishment

VEGETATED GABIONS

- Gabions interspersed with establishing vegetation
  - Similar to joint planting
- Less re-grading necessary
- Good for high velocity flow
- Highly complex



Vegetated Gabion Baskets (TRB, 2004)

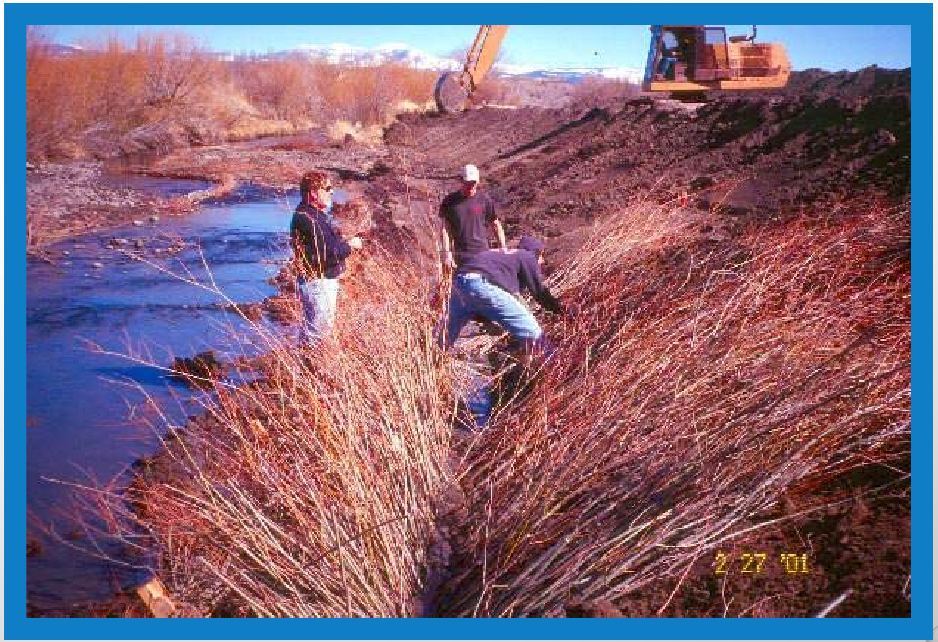
BRUSH LAYERING/VEGETATED GEOGRIDS

Vegetated Geogrids in Construction (TRB, 2004)

- Alternating layers of vegetation and earth
  - Geogrids offer more protection
- Very effective establishment
- Better soil drainage
- Little limitation data

BRUSH MATTRESSING

- "Blanket" of woody brush
- Double establishment
- Works well in areas where willows thrive
- Requires toe protection



Installation of Brush Mattress (TRB, 2004)

IN-STREAM TOE PROTECTION

Tree Revetments (TRB, 2004)

- Tree revetments
  - Desirable where large woody debris is normal
- Rock vanes
  - Direct forces away from bank
  - Create habitat

SUMMARY OF METHODS

Table 3: Summary of Methods - Greenbank (TRB, 2004)

Method	Protects		Combinations Possible	Complexity	Labor Intensity	Cost	Maintenance
	Upper Bank	Toe					
streambank re-grading	x	x	yes; necessary	low	moderate	low	low
vegetation	x	x	yes; necessary	variable	low	low	moderate
live stakes	x		yes	low	low	low	low
joint planting	x	x	yes	moderate	high	high	high
brush layering	x		limited	moderate	moderate	moderate	low
live fascines	x		yes	moderate	low	low	very low
vegetated geogrids	x		limited	high	high	high	very low
brush mattress	x	x	yes	moderate	moderate	moderate	moderate
tree revetments		x	yes	moderate	moderate	moderate	high
fiber rolls		x	yes	low	variable	variable	high
vegetated gabions	x	x	limited	moderate	high	high	high
rock vanes		x	yes	moderate	high	high	low
erosion control blanket	x		yes	low	moderate	variable	low

PROPOSAL – GUIDELINE DOCUMENT

- Typical watershed streambank characteristics
- Discuss recommended treatments
- Description and design guide

Live Brush Layering (TRB, 2004)

PROPOSAL – RECOMMENDATION SHEET

- User Inputs
  - Hydrologic characteristics
  - Soil type
  - Stage of channel evolution
  - Erosion processes present
  - Percent existing vegetative cover

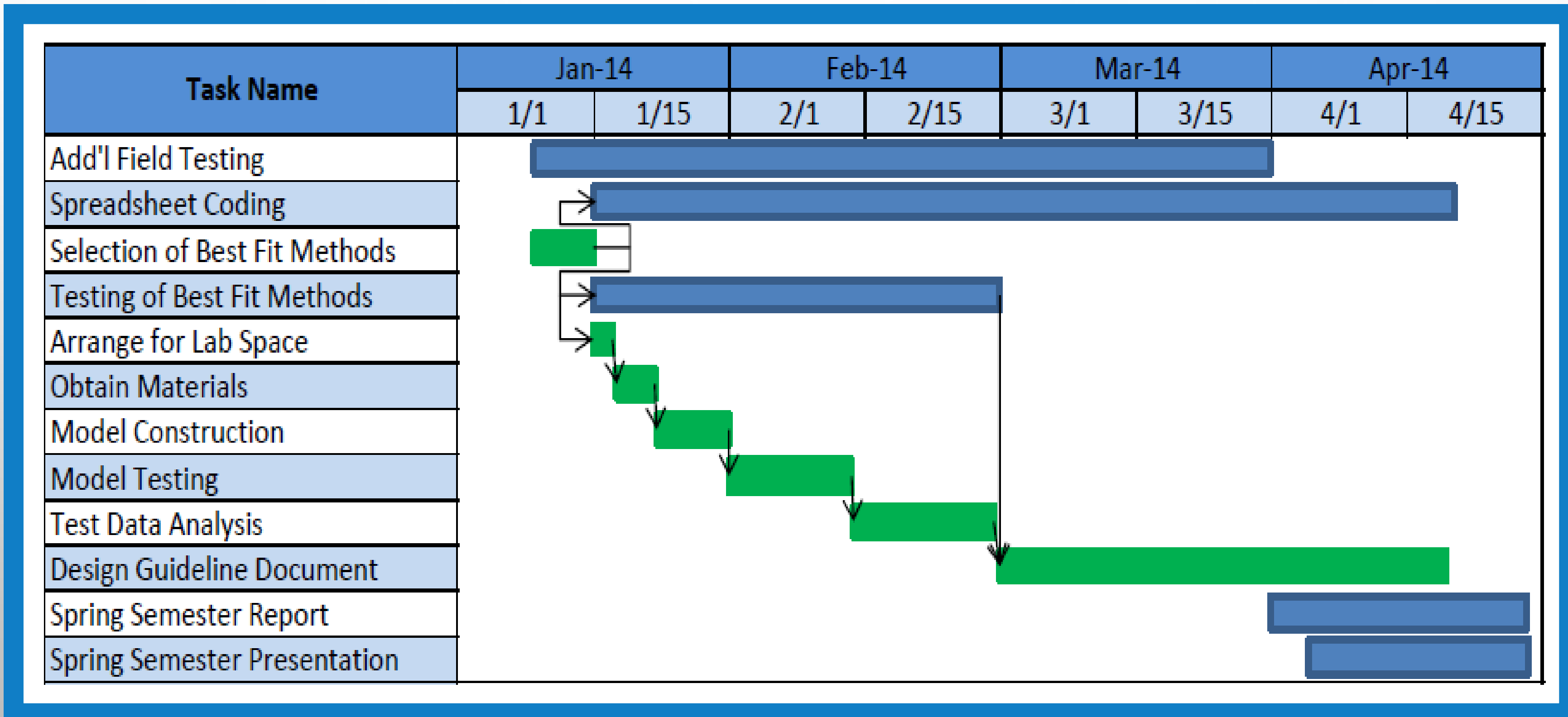
- Program Outputs
  - Best recommended method
  - Pros and cons for various methods
  - Specific design considerations

DESIGN IMPACTS

- Prolong life of John Redmond Lake
  - Drinking water reservoir
- Create habitat
  - Flint Hills Wildlife Preserve

Newly Restored Streambank (TRB, 2004)

SPRING SCHEDULE—GANTT CHART



SPRING SCHEDULE—BUDGET

- Spring field expedition
  - Transportation and lodging—$200
  - Food—$135
  - Gasoline for the pump—$15
- Modeling supplies—$300
- Total estimated spring expenses—**$650**

SUMMARY

- Spring semester
  - Wrap up technical analysis/data collection
  - Choose methods and method-specific designs
  - Create comprehensive design manual
  - Create recommendation program

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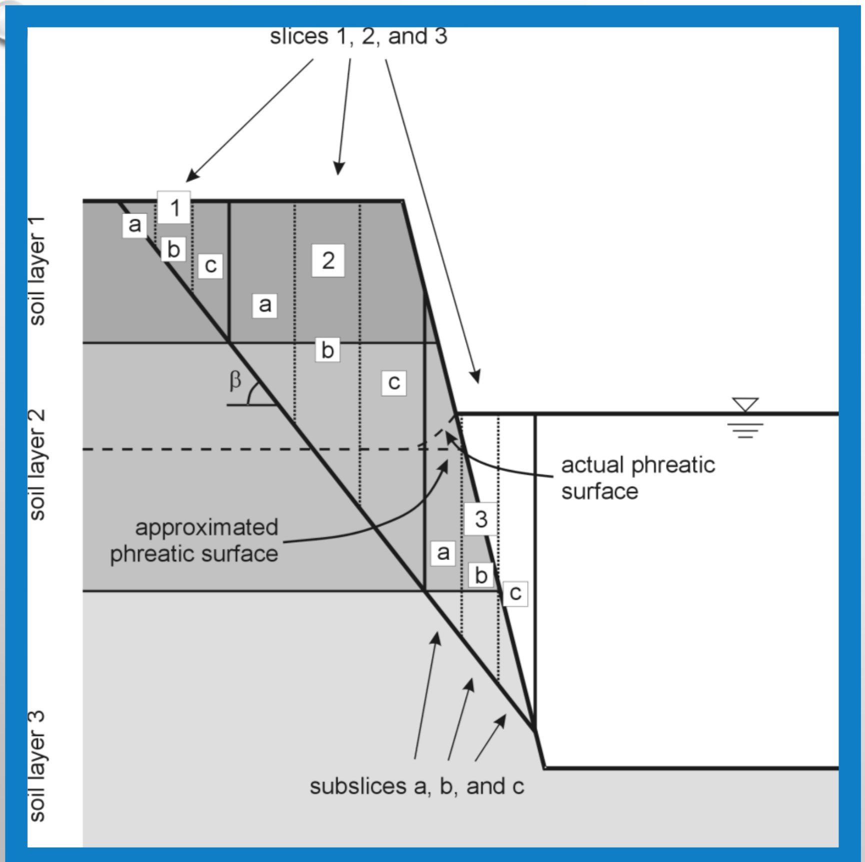
QUESTIONS?

BSTEM: VERTICAL FAILURE ANALYSIS



- Slices and sub-slices
- Evaluates active normal and shear forces
- F_S calculation is iterative process

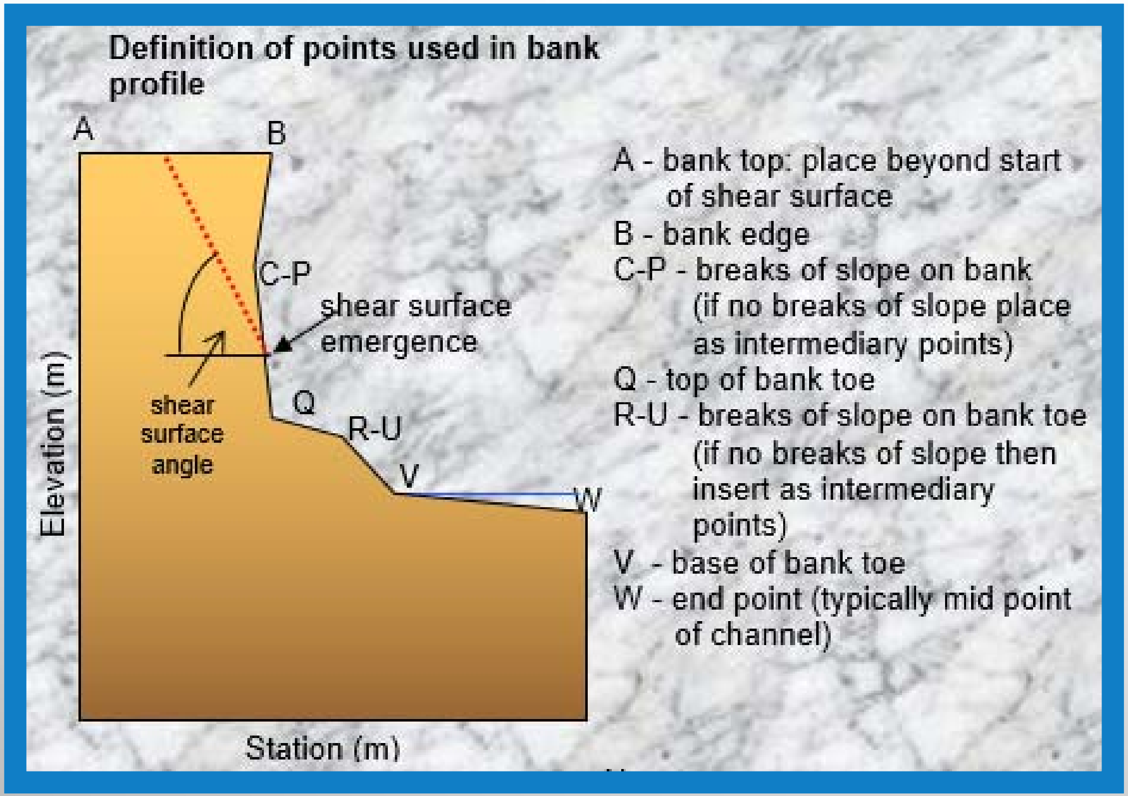
Vertical Slices Example (Langendoen, 2013)

BSTEM: CANTILEVER SHEAR FAILURE

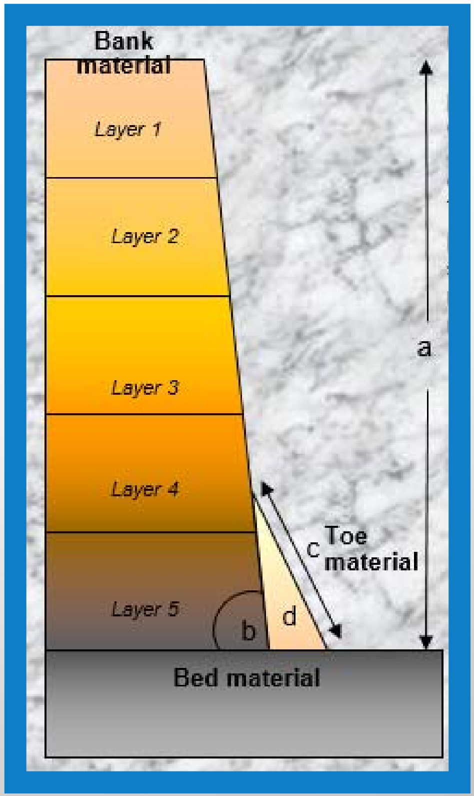
- Fs calculation
  - Shear strength of soil to weight of cantilever
  - Correction factor for Fs

Overhanging soil held in place by roots, Site 33

BSTEM: BANK PROFILE SIMULATION



Option A (Langendoen, 2013)



Option B (Langendoen, 2013)